NGST Architectures

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Next Generation Space Telescope

NGST

Observatory Level Parametric Trades

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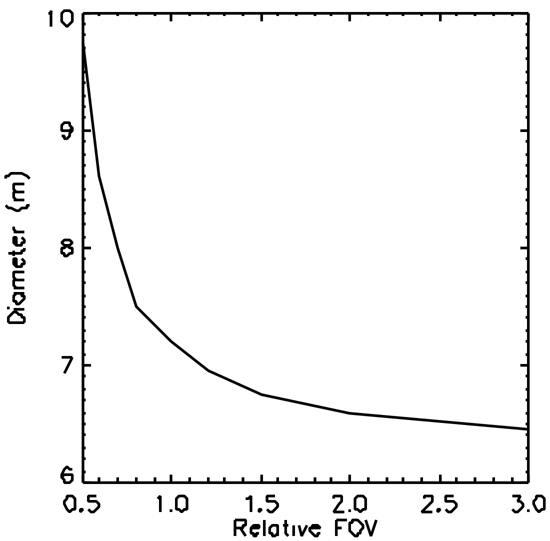
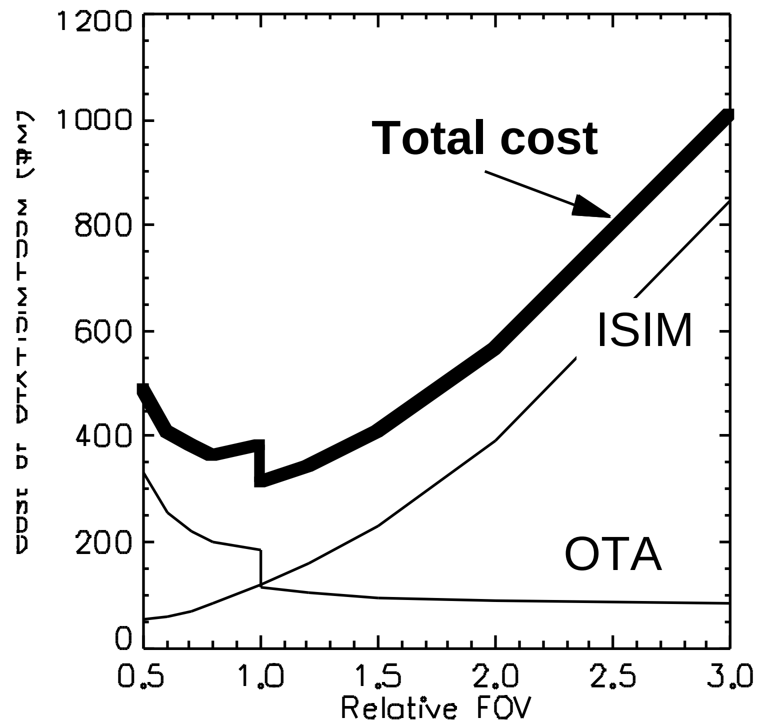
Determination of the main observatory parameters

- NGST is an “Observatory” I.e. a multipurpose facility where desired observations can have conflicting requirements. NGST cannot be optimum for all types of observations and a compromise must be found.
- The Design Reference Mission is used to determine the optimal set of observatory parameters: (diameter, configuration, detector, temperature etc..) based on cost.
- First-order cost models
  - OTA: a $D^{2.7}$
  - ISIM: cost grows as the physical size of the field of view, I.e. FOV measured in solid angle on the sky x D^2 (critical sampling)
  - cost of reducing detector noise below current level is a power law with adhoc exponent
  - SSM: $a + bD^3 + cD^2$ (D^3 for items driven by mass such as the ACS, D^2 for items driven by size such as the sunshield)
  - cost of passively cooling: proportional to the number of shield layers

DRM-based system trades: field of view





- **Because of the large survey content in the DRM, a smaller telescope size can be traded for a larger FOV**
- **But a floor is reached because of pointed observations**
- **A minimum cost is reached because of this saturation and the fact that large FOV cost are significantly**

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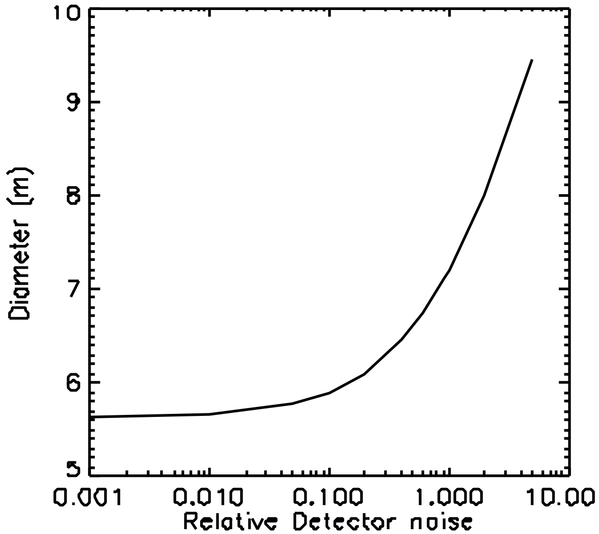
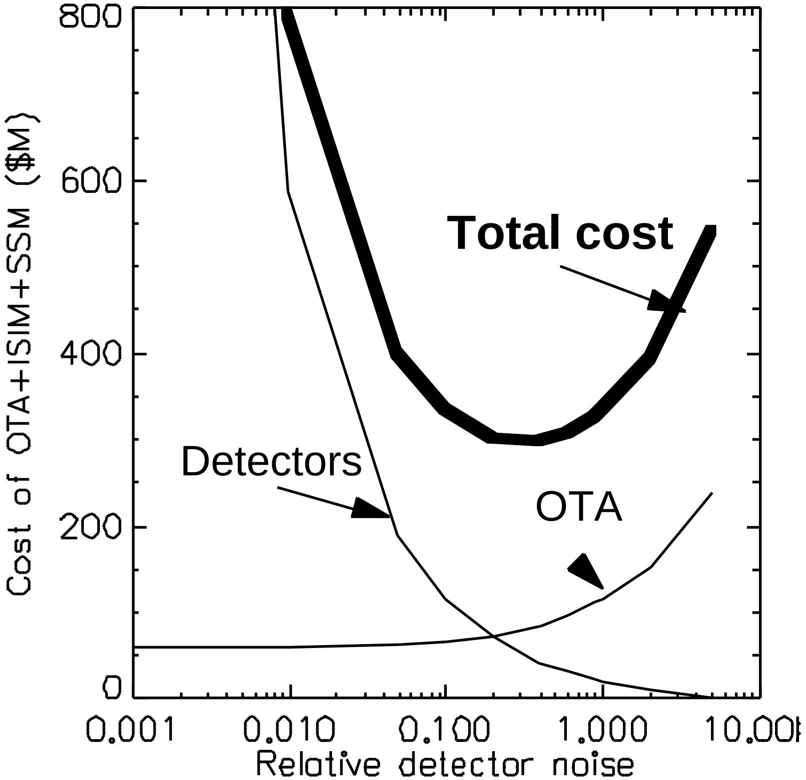
DRM-based system trades: detector noise





- **Lower detector noise allows for decrease in PM area, but a floor is reached because of the zodiacal light**
- **At about a factor of 10 from the present state of the art, the cost of decreasing the detector noise outstrips the savings in PM size**
- **A factor of 2 additional noise reduction over the current yardstick expected value could lead to reduced overall cost (slightly smaller telescope)**

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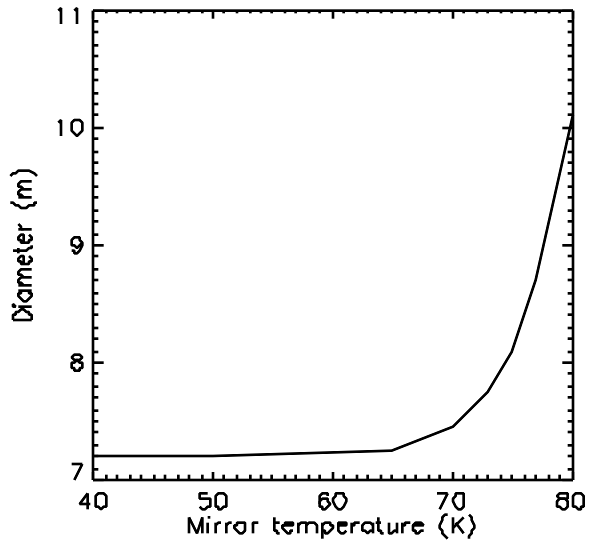
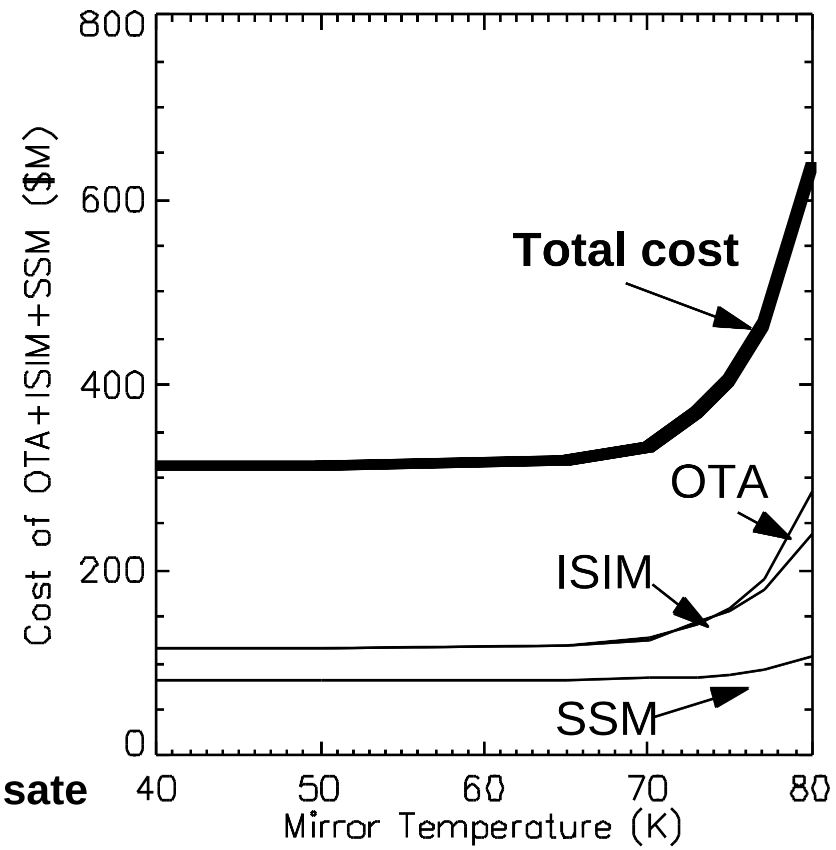
DRM-based system trades: mirror temperature





- **To keep constant sensitivity, the diameter has to increase to compensate for increased thermal background**
- **Lowering mirror temperature below 70K does not lead to lower overall cost**
- **Increasing the OTA temperature above 70 K does not reduce the overall cost because the sunshield size has to increase and offset the reduction in sunshield layers**

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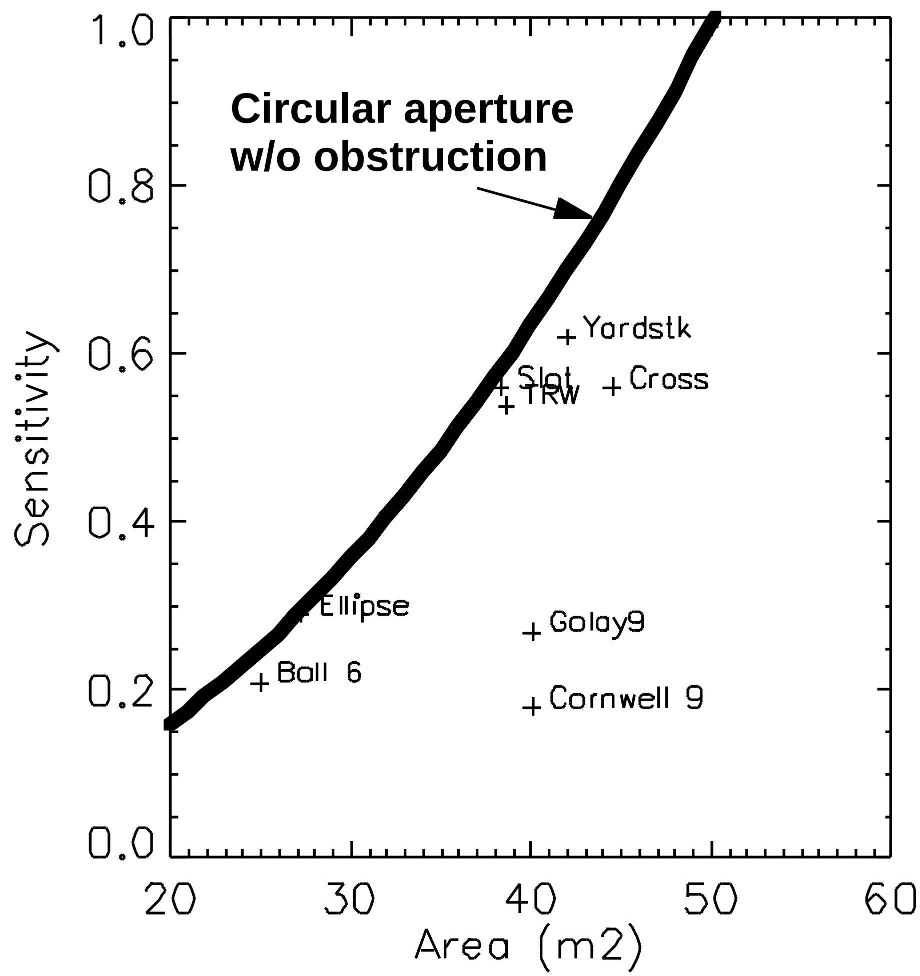
Comparison of various aperture configurations

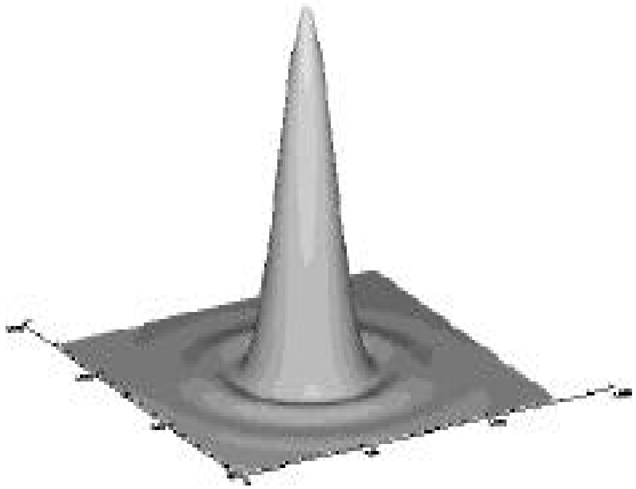
Comparison of various aperture configurations launchable in an Atlas-II

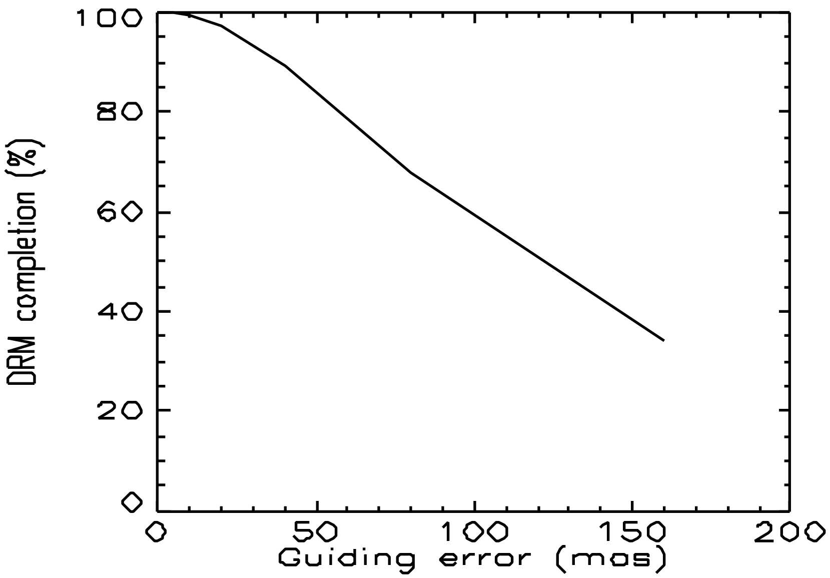
- **Fairing diameter of 3.6 m**

- **Mirror area limited to 45 m^2 because of mass limitation**



Effect of Jitter





Line of sight jitter blurs the psf and results in:

- **loss in resolution**
- **loss in sensitivity**

The DRM is dominated by NIR observations. Guiding should be better than 10 mas.

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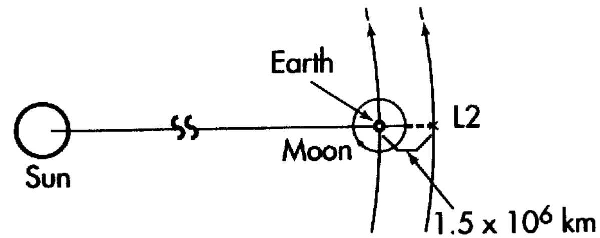
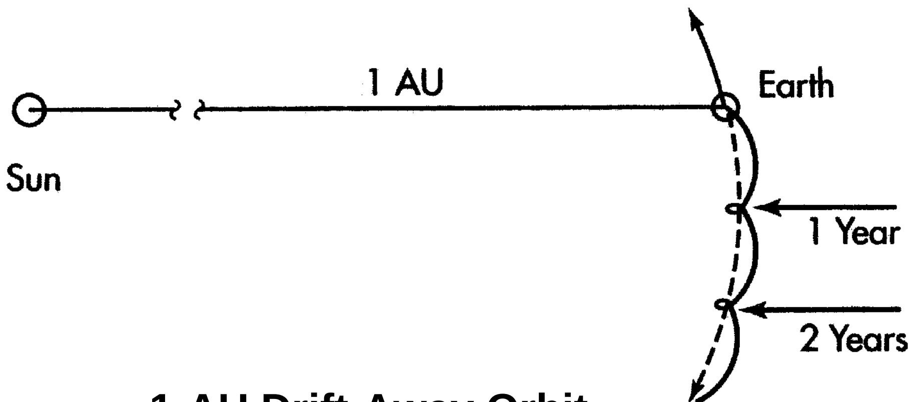
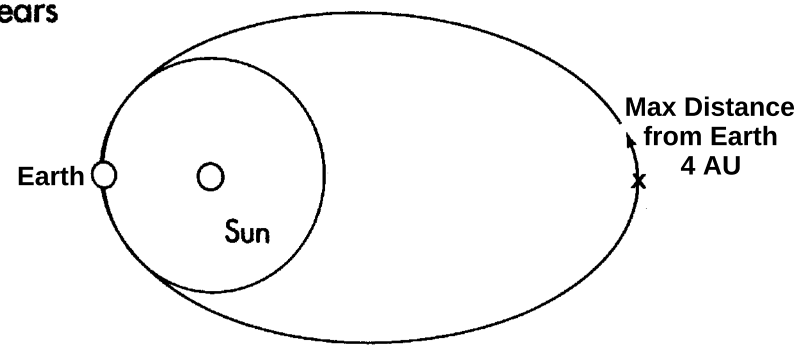
Orbit Trades



L2 Lagrangian Point



1-AU Drift-Away Orbit
(~1AU from Earth at 10 Years)



1 AU x 3 AU Solar Orbit
(2.83-Year Period)

Heliocentric 1 x 3 AU Orbit

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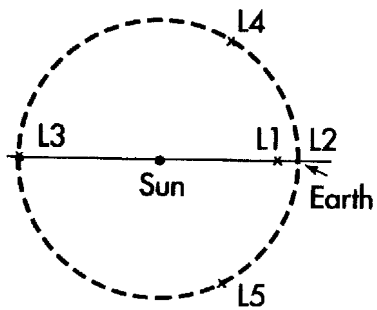
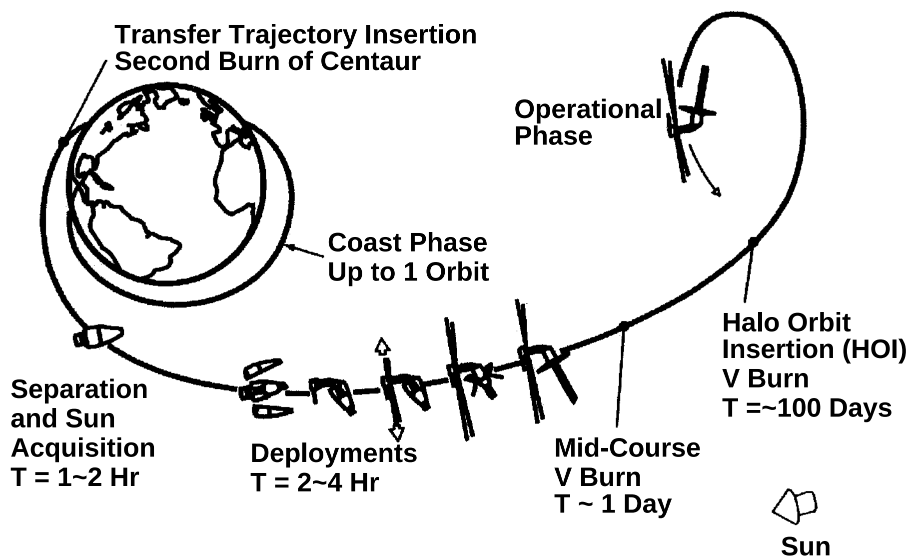
Orbit trades

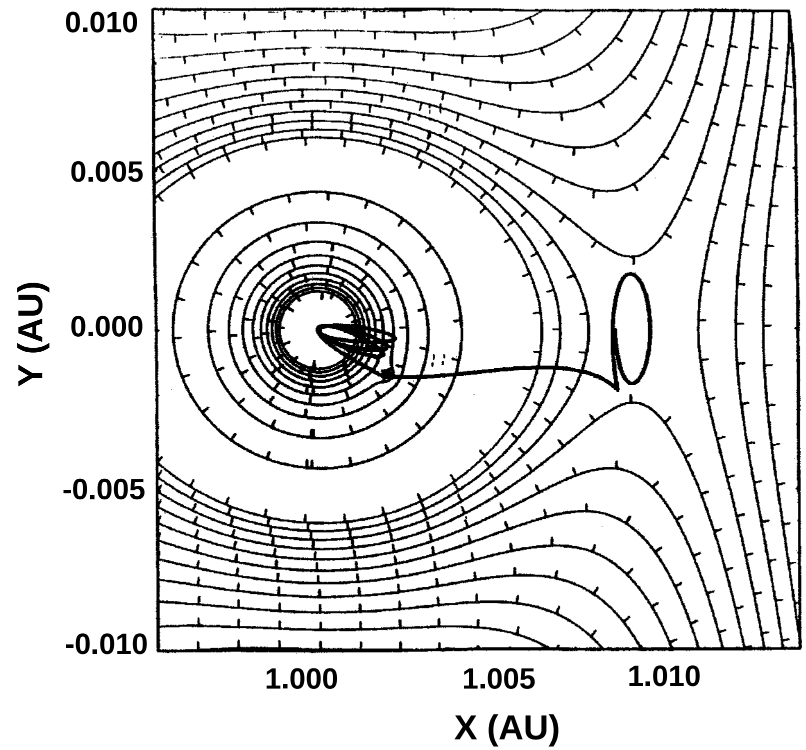
Orbits	Zodiacal Light	Power	Communi - cations	Thermal	Observing Efficiency	Station Keeping
LEO, GEO	Low Toward Poles	Standard	Standard	Active Cooling Required for 60K	Low	Drag & Mag Torques in LEO
L2 Direct Injection	Low Toward Poles	Standard	Slightly More Difficult	Passive Cooling to 60K	High	Small Delta V 1~4 m/s/ yr
1 AU Drift Orbit	Slightly Lower Than L2	Slightly Higer Than L2	More Difficult	Slightly Cooler Than L2	Medium to High	No Delta V
1 x 3 AU Elliptical	Much Lower at 3 AU	10% of L2 at 3 AU	Much More Difficult at 3 AU	Much Colder at 3 AU	Medium	Course Correct- Ion Delta V

Launch and orbit maintenance



Lagrange Points of the
Sun-Earth System





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NGST typical characteristics

NGST main characteristics

Item	*Value*
Scientific performance	
Wavelength coverage	0.6 to 30 microns
Aperture diameter	8 meters
Sensitivity	4 nJy in 10,000s at 2 microns, S/N=10, BP20%
Resolution	diffrac. limited at 2 microns (50mas)
Science instruments	cameras, multiobject spectrograph
Field	NIR: 4’x4’ (imaging) 3’x3’ (spectrograph) MIR: 2’x2’ (camera)
Fine pointing	10 mas
Mission aspects	
Mass	3300 kg (to L2)
Spacecraft pointing accuracy	2”
Power	800W
Mission lifetime	5 years nominal- 10 years goal
Orbit	Sun-earth Lagrange 2 Halo orbit
Sky coverage	Yearly: full sky Instantaneous:25%
Launcher	Atlas II ARS

Current concepts

Current Architectures

	Diameter	Aperture configuration	Wavelength coverage(μ)	Orbit	Instantaneous Sky coverage	Launcher
Yardstick	8m	Petals	0.6-25	L2	25%	Atlas-II
BALL	8m	Table top	0.6-25	L2	25%	EELV-Heavy
TRW	8m	Hexagons	0.4-25	L2	50%	Atlas-II
L-M	6m	Monolithic	0.4-12	1x4AU	20%?	Proton

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Yardstick Concept

Subsystems Trade Studies

A number of trade studies were performed as part of the 1996 study:

- Aperture configuration (unfilled, T, slot etc…)
- Mirror Deployment system
- Mirror blank material and structure
- Orbit (drift vs L2)
- Attitude control (thruster vs RW)
- Cocoon or not
- Mirror coatings
- etc…

Choices are revisited as the study progresses

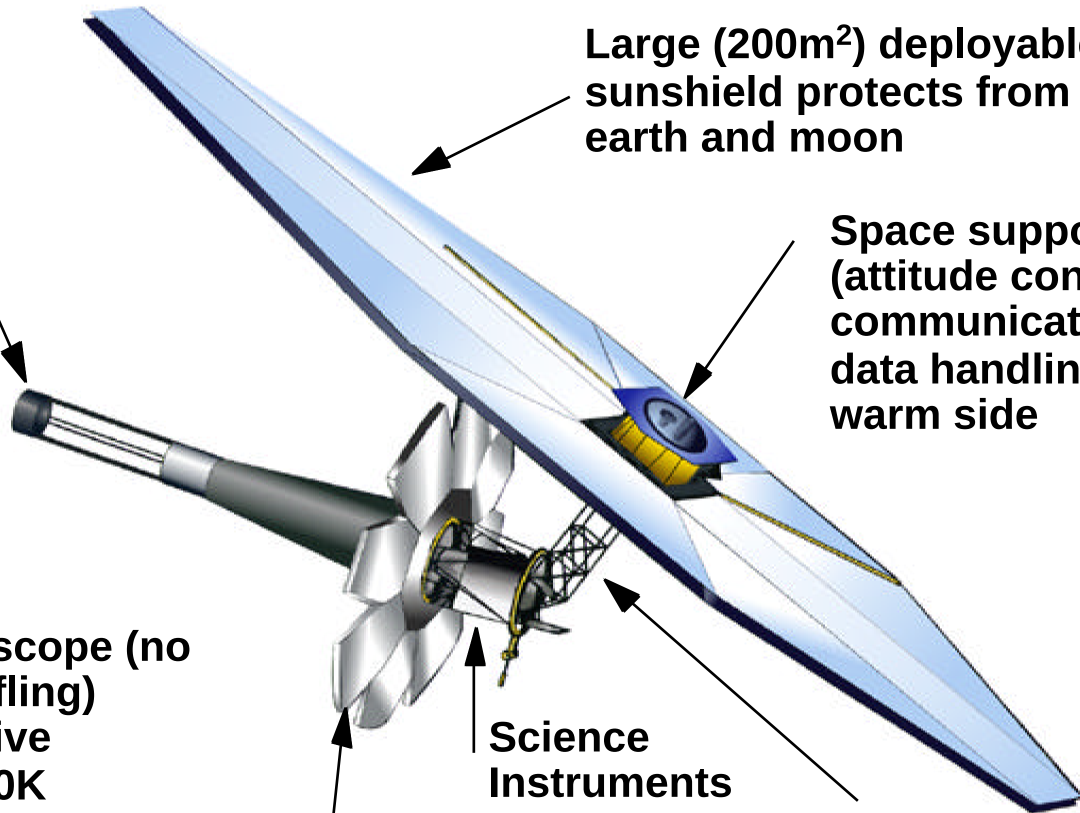
The Depth of the Yardstick Mission Study Is Not Uniform

- We have emphasized the areas where NGST is out of the ordinary
  - Primary mirror
  - secondary support system
  - optical design
  - detectors
  - instruments (serves as input to optical design and packaging)
  - dynamics
  - vibration control
  - attitude control system (large flexible structure)
  - active optics (FSM, DM, PM figure control)
  - thermal (passive cooling)
  - sunshield
  - autonomous operation
  - cryocooling
  - meteorites
  - contamination
- The areas which have received less attention because standard approaches and state of the art will suffice:
  - spacecraft
  - communication
  - data handling
  - propulsion
  - flight dynamics

Design philosophy

- Nominal operation of 5 years - 10 years expected
- No on-orbit maintenance (economical justification doubtful - LEO not an option for an infrared telescope)
- Functional redundancy (multiple instrument channels, mirror actuation, two-FSM back to back)
- Extensive use of active optics (reduces optics cost and mass, eases-up attitude control system)
- Use same material for optics and telescope structure to avoid CTE mismatch problems (ambient to cold) -- not all agree ---
- Use science camera for guiding (saves cost) -- not all agree ---
- On-board acquisition of guide stars (saves on ground operations and time overheads)
- individual focussing for each instrument

Reference Concept



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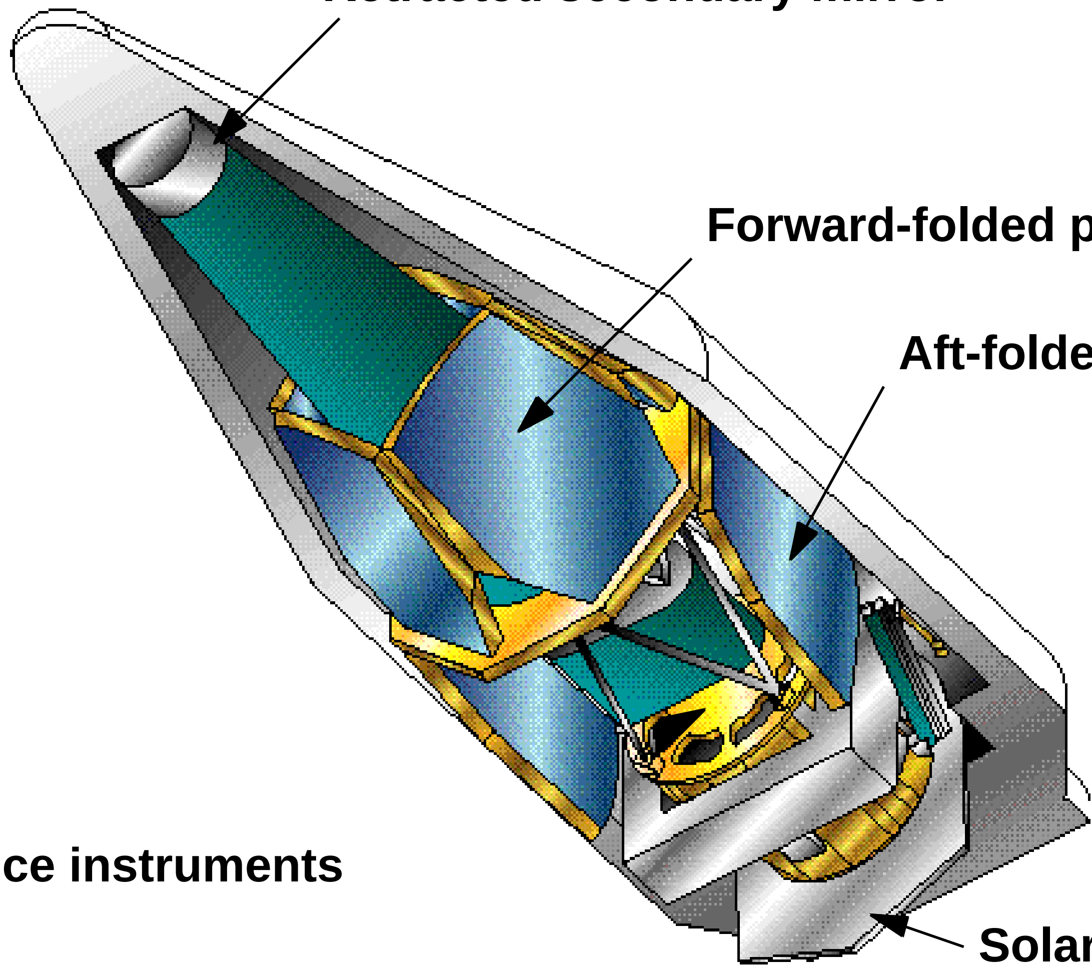
Launch configuration



NGST folded for launch in an Atlas II fairing

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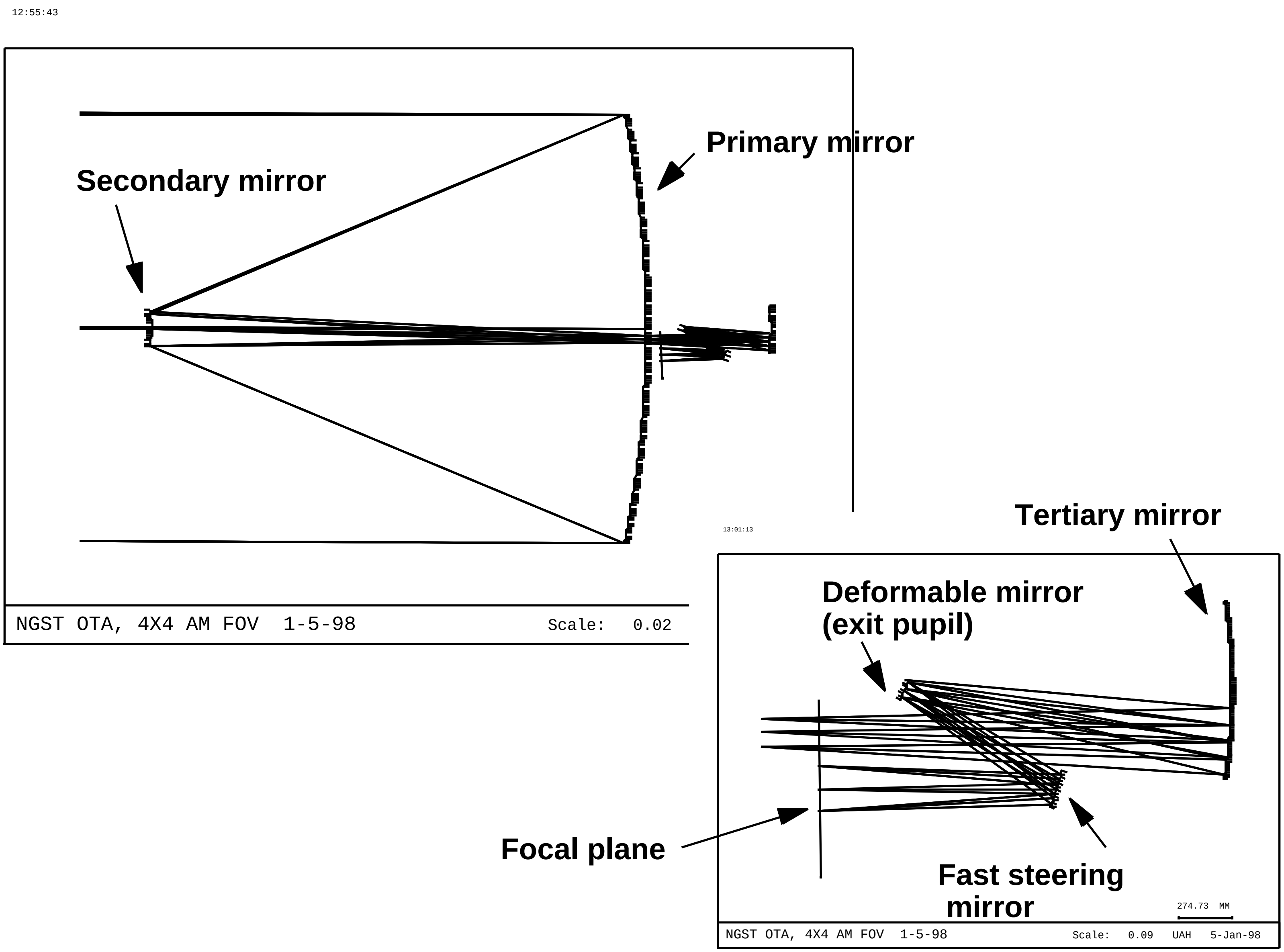
Optical diagram



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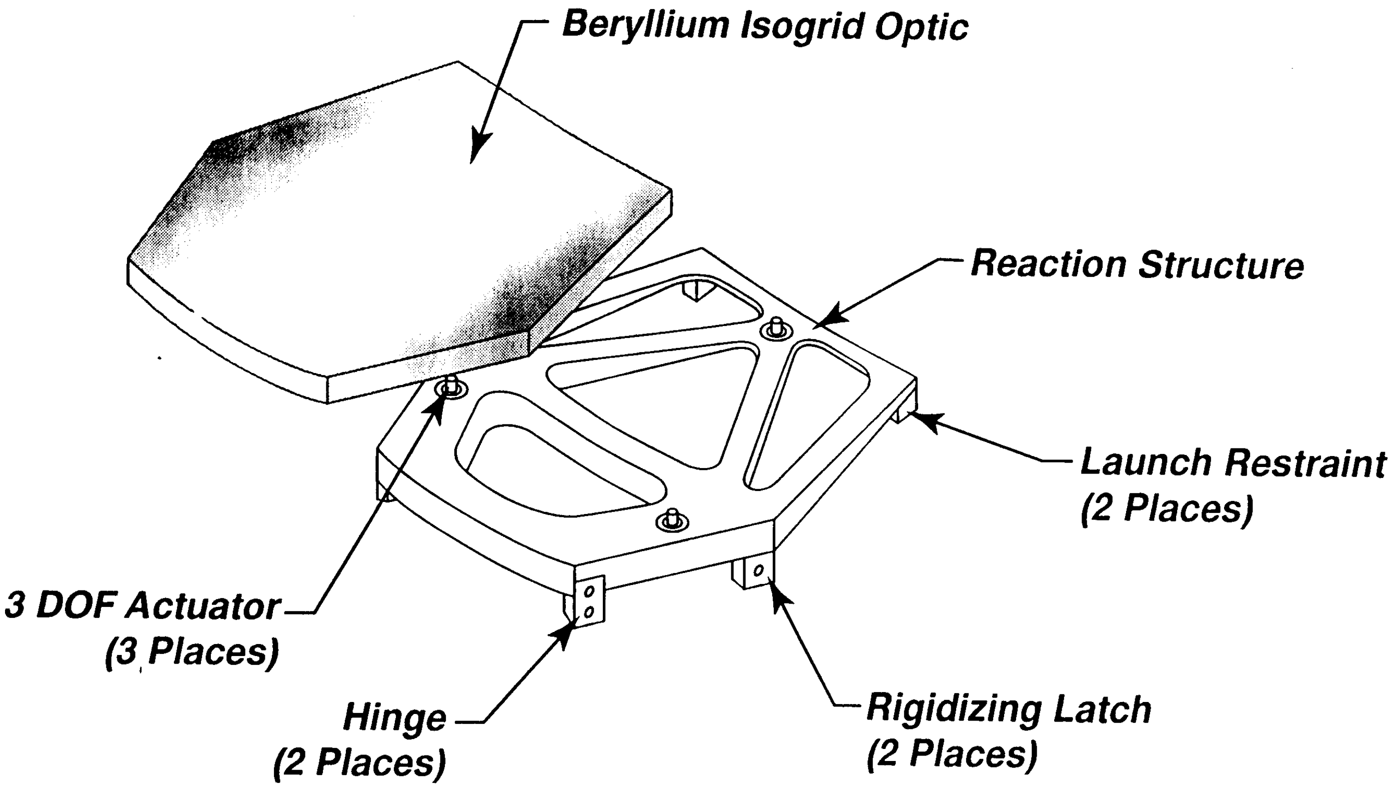
Typical beryllium petal assembly



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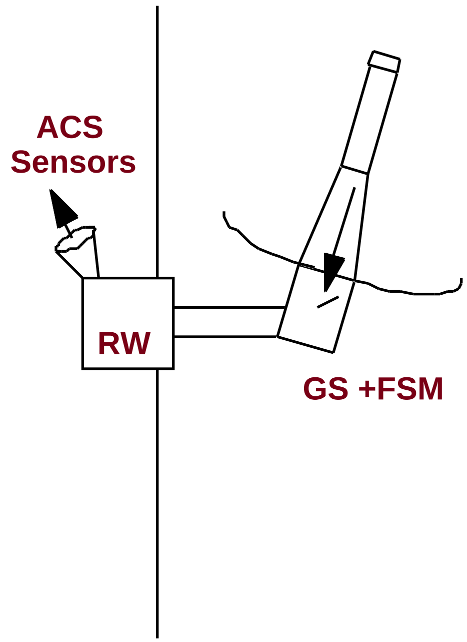
Attitude control rationale



1. SSM needs to be warm for electronics and reaction wheels
2. SSM must be separate from OTA to minimize heat conduction
3. Isolation truss flexibility would lead to ACS unstability if the sensors were on OTA while RW are in SSM. Sensors and RW must be colocated in the SSM
4. The ACS is not capable to give OTA stability to milliarcsecond level (body pointing is NOT an option for our NGST “offset” design)
5. This requires an image compensation system (guide star sensor and FSM) in OTA.

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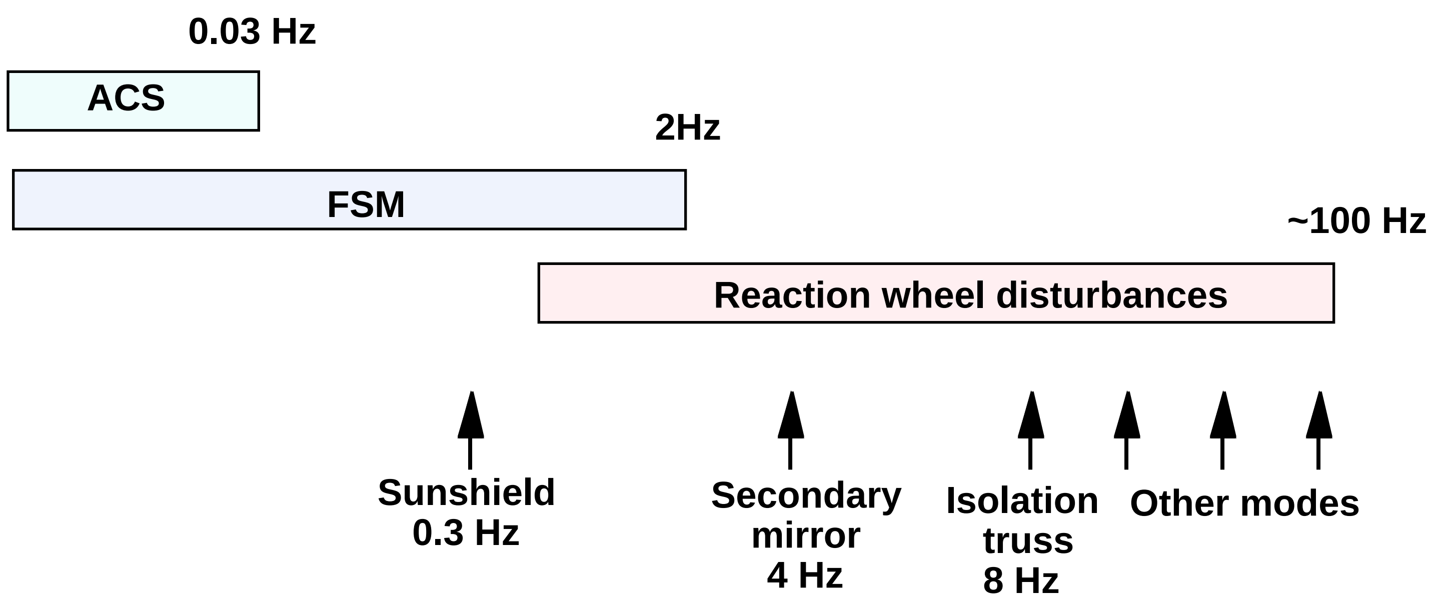
Pointing control system

Control bandwidth compared



- The ACS has no authority to control any of the flexible modes
- The FSM can suppress the sunshield mode
- Excitation of the higher modes must be minimized

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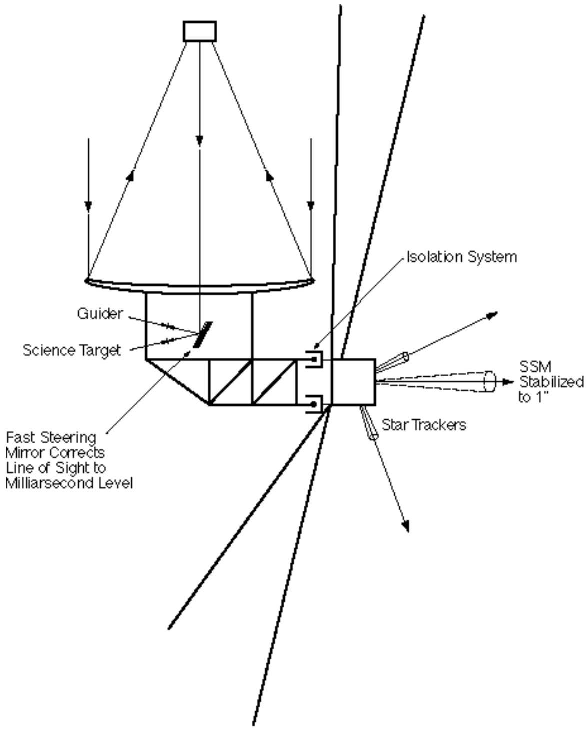
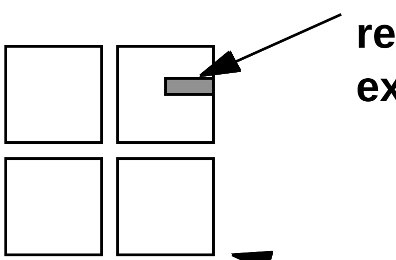
Guiding system



- 95% probability of finding one guide star requires an average of 3 stars in the field.
- At the galactic poles, one can find 16.5 magnitude stars in a 4'x4' field.
- Science camera can be used for guiding

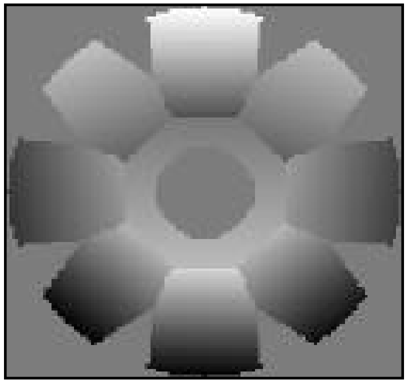


A 10x10 pixels area around the guide star is read at 100 Hz. The 512x128 readout area is excluded from the science observation

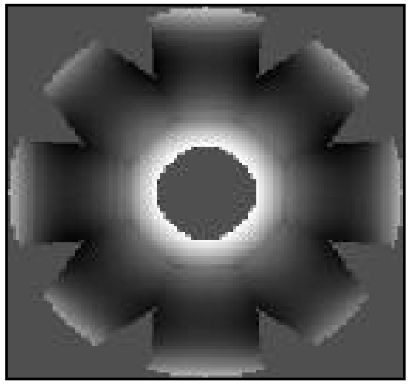
4' x4' guide star acquisition field

Control of the segmented mirror

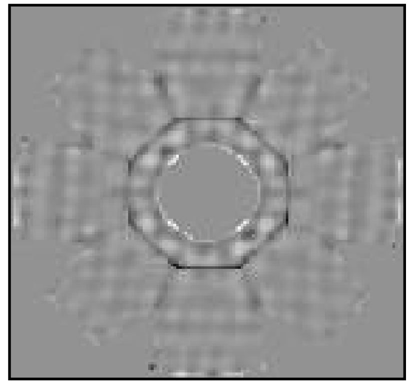
Cold-Figured Primary Mirror



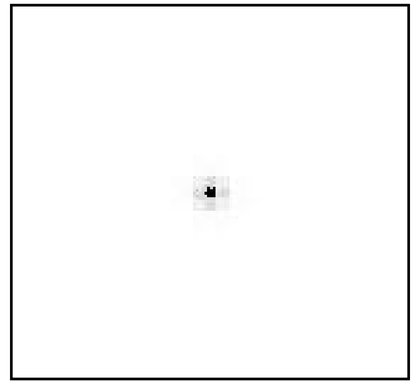
Raw on-orbit WFE
WFE = 34 μm



Following segment control
WFE = 717 nm
4DOF/segment actuation



Following DM control
WFE = 33 nm



Following DM control
SR = 96 %
$\lambda = 1\ \mu m$
Detector sampling

Example: Ground-to-Orbit thermal effects

Optical control improves cold-figured PM WFE performance to within requirements

- **Segment control improvement factor = 47**
- **DM control improvement factor = 22**
- **Total control improvement factor = 1120**

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Yardstick mission study: status and conclusions

- Yardstick study to be complete by April 1998 (except for costing)
- First- phase End-to-end modeling (ref. later presentation) is essentially complete.
- Conclusions so far:
  - the reference concept meets the science goals
  - optical design provides adequate field and image quality
  - active optics able to correct for ground to orbit and on-orbit structural and temperature effects
  - sunshade provides required mirror temperature (50 K)
  - current ACS/design is adequate but requires either quiet wheels (HST type) or isolation
  - end-to-end modeling has allowed to pinpoint goals of technology development
- Current ("in depth") study will be followed by ("broad") study of alternate subsystem designs or concepts, e.g.
  - alternate mirror materials
  - alternate attitude control (FEEP etc..)
  - off-axis optical layout

TRW ARCHITECTURE

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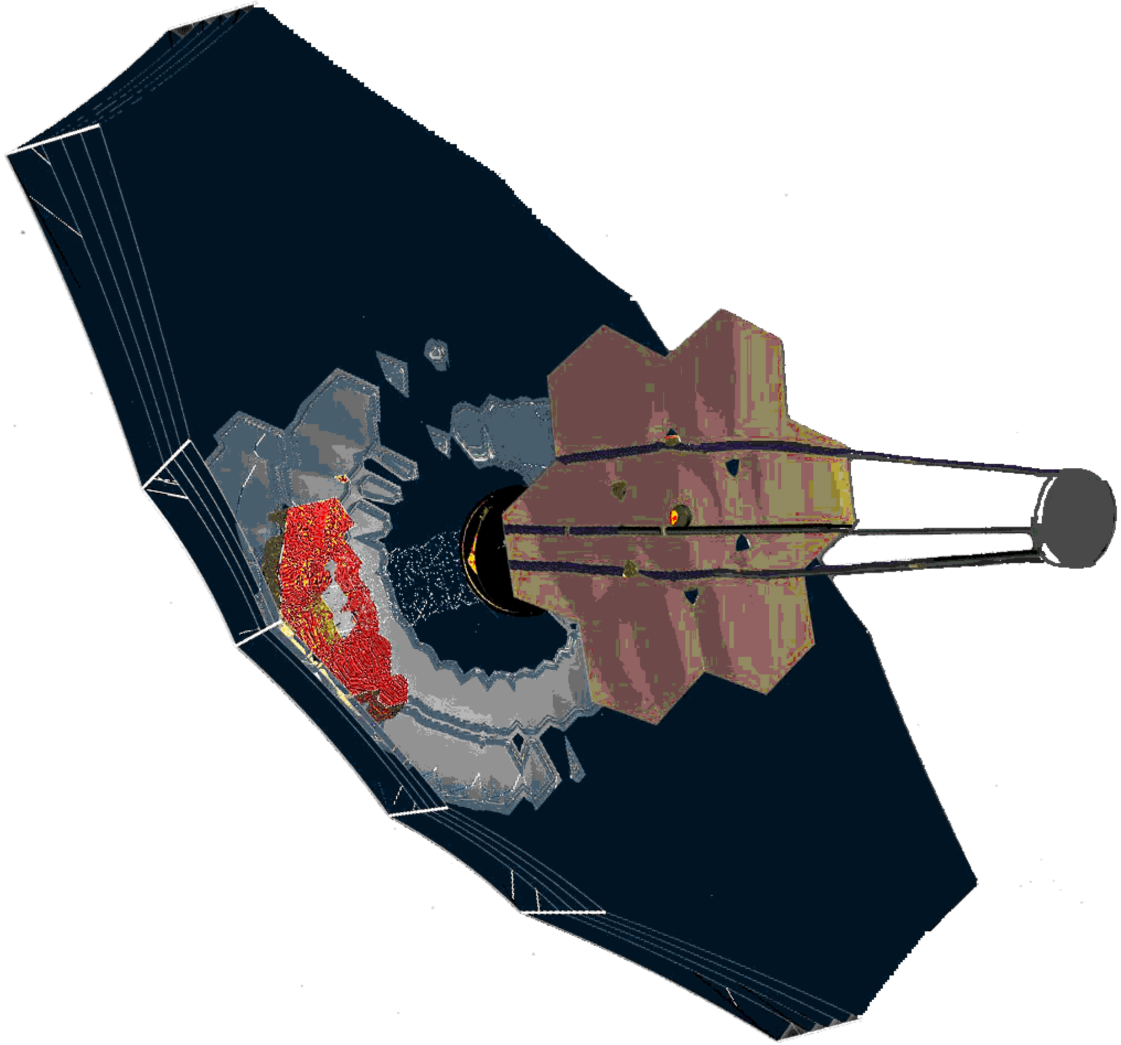
TRW Concept



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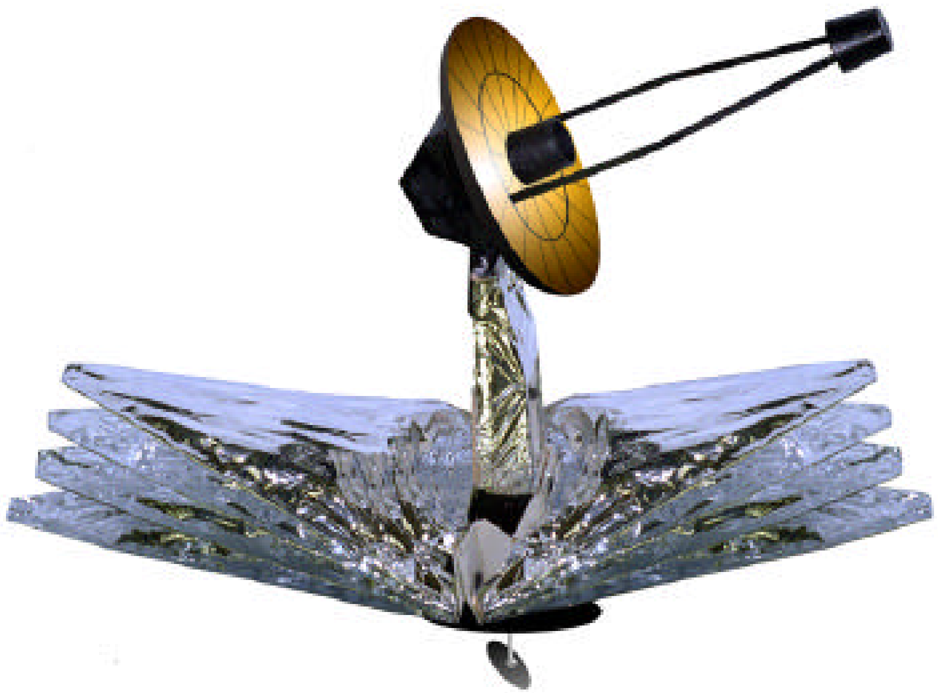
BALL AEROSPACE ARCHITECTURE

Ball Aerospace Concept



LOCKHEED MARTIN ARCHITECTURE

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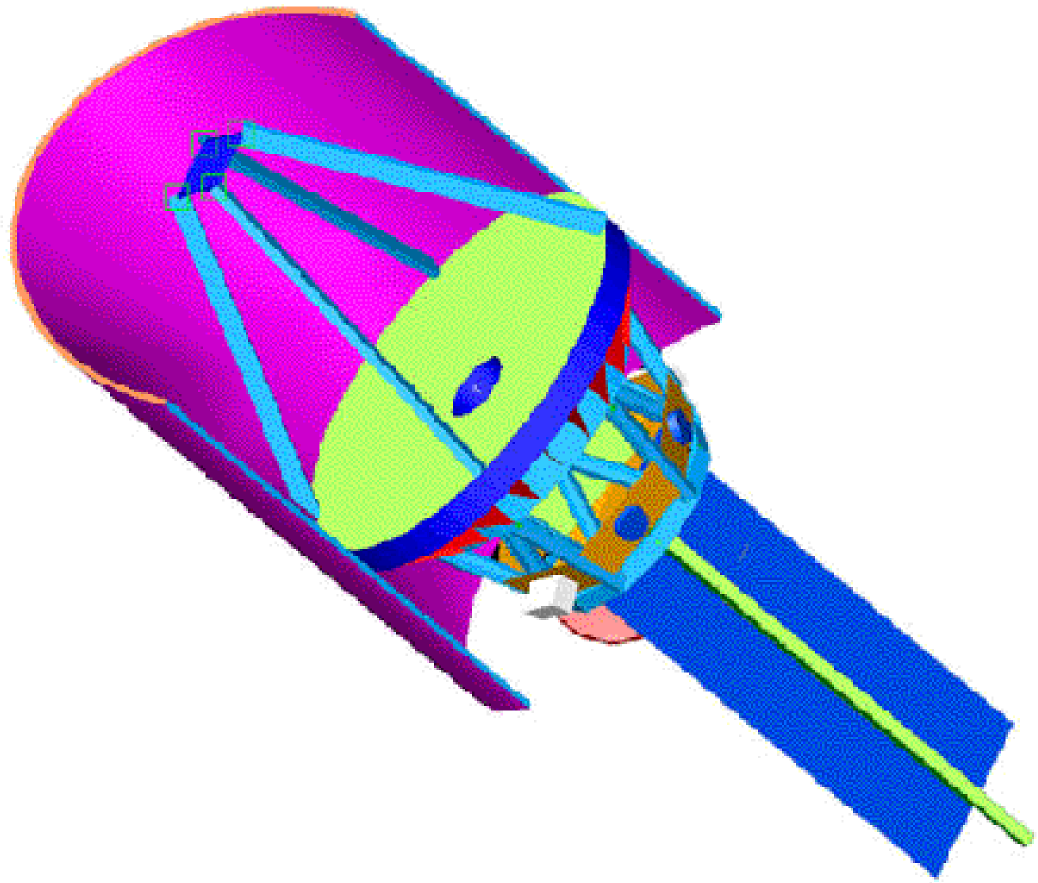
L-M 6m monolith concept



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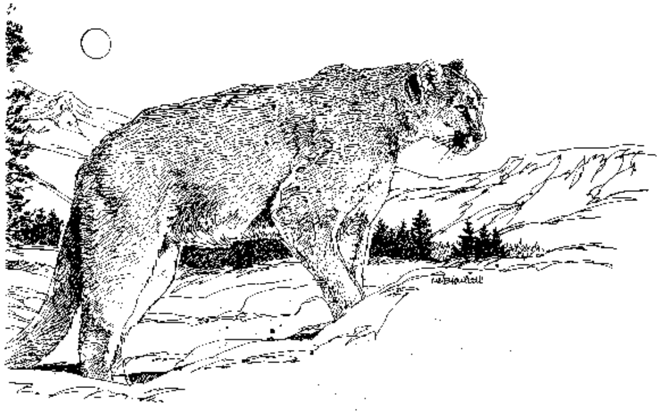
Conclusions

- All 4 concepts being developed are very promising and explore a wide range of technical options. This gives high confidence in the technical optimization and feasibility
- All players are fully aware that <u>cost feasibility</u>, not technical feasibility, is the real issue and current designs are cost effective
  - wavelength coverage limited to the essential (no UV - no far infrared)
  - visible available on an "as is" basis (with degraded image quality - using NIR detector)
  - no dedicated guider
  - integrated science instruments with lots of commonality (see R. Burg presentation later)

NGST is <u>not</u> a Xmas tree



NGST is <u>mean and lean</u>

INTEGRATED SYSTEMS MODELING

Gary Mosier
Goddard Space Flight Center

David Redding
Jet Propulsion Laboratory, California Institute of Technology

January 14, 1998

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Integrated Systems Analysis

CONCEPTUALIZE → **OPTIMIZE** → **VALIDATE**

Mission Life Cycle

GSFC IMDC and JPL PDC toolsets

- *very simple analytic models*
- *mission-level parametric analysis*
- *spreadsheet-centric, some CAD tools*
- *oriented toward mission and spacecraft analysis*

NGST Matlab-based tools (IMOS)

- *medium complexity analytic models*
- *subsystem-level parametric analysis*
- *flexible, programmable software environment*
- *linear, non-linear, statistical, simulation*
- *multidisciplinary design optimization with science & cost metrics*

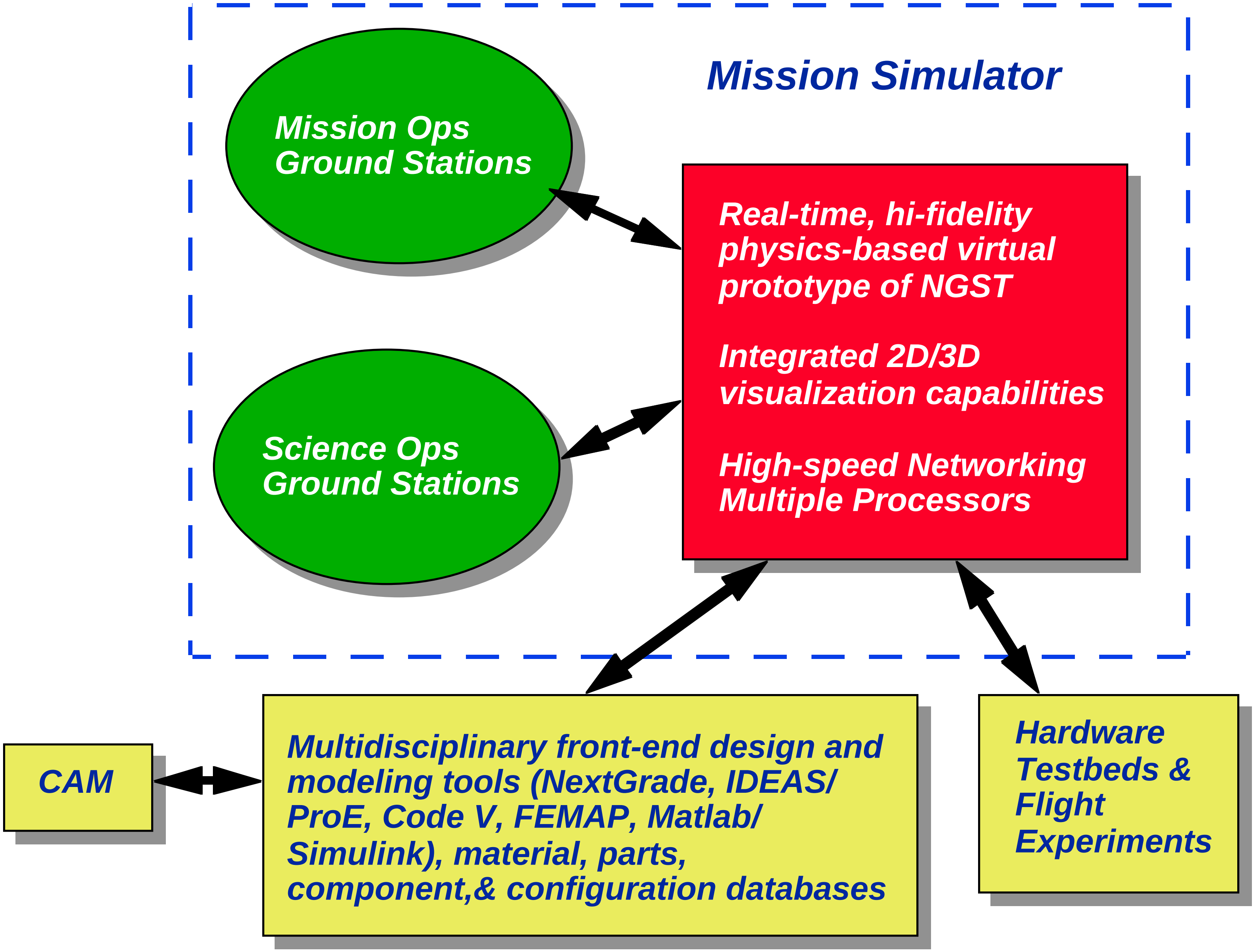
Detailed Design and Validation Tools

- *“industry standard” & legacy tools*
- *cumbersome for trades and optimzation process*

NGST Virtual Prototype

- *think “flight simulator”*
- *more on next chart*

A Vision For Future Capabilities



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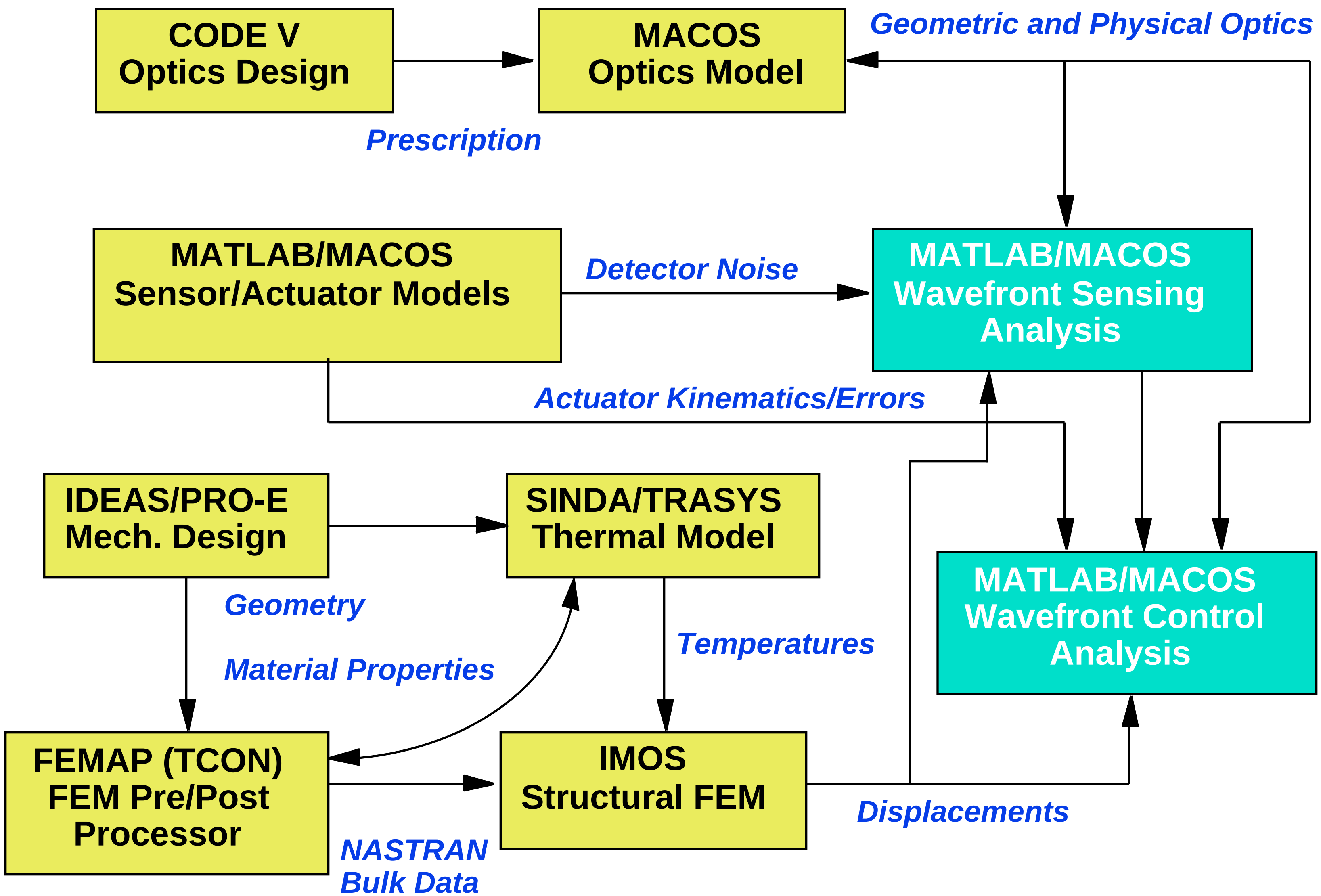
Integrated Modeling Flow - Static Analysis



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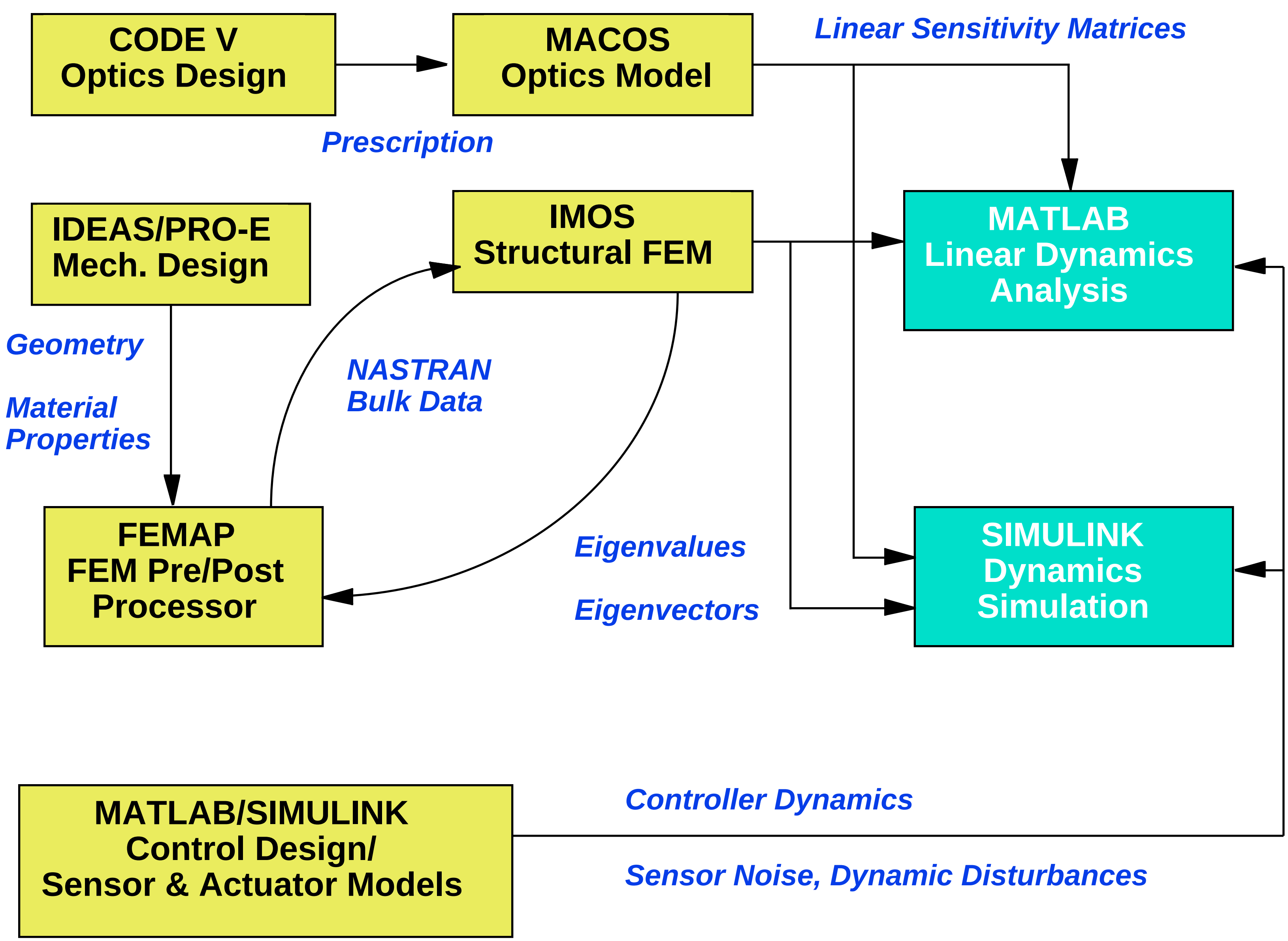
Integrated Modeling Flow - Dynamic Analysis



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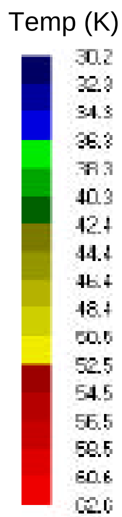
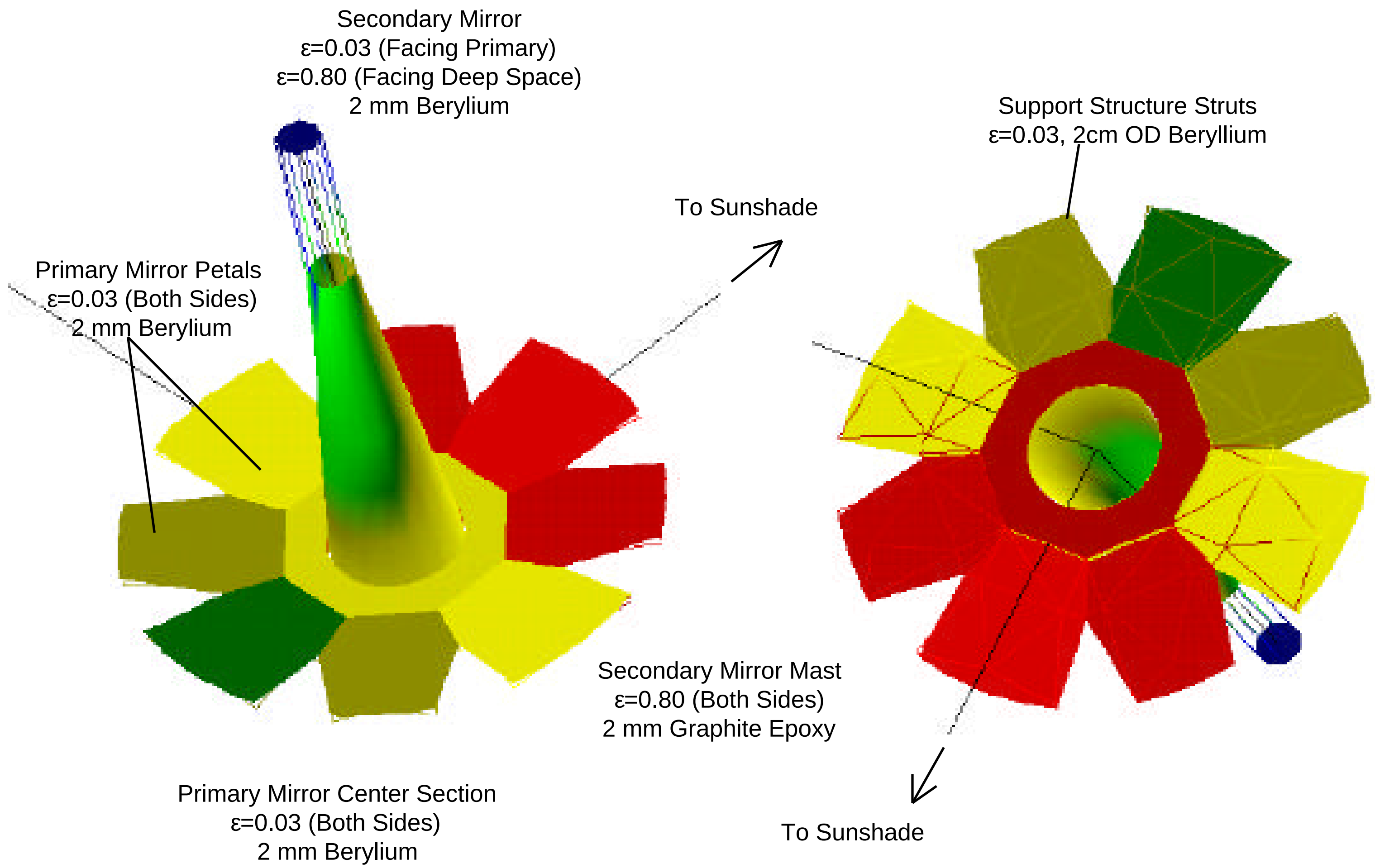
NGST OTA Steady State Thermal Model Results

Petal-to-petal gradients produce structural deformations which in turn produce wavefront error -- see next chart





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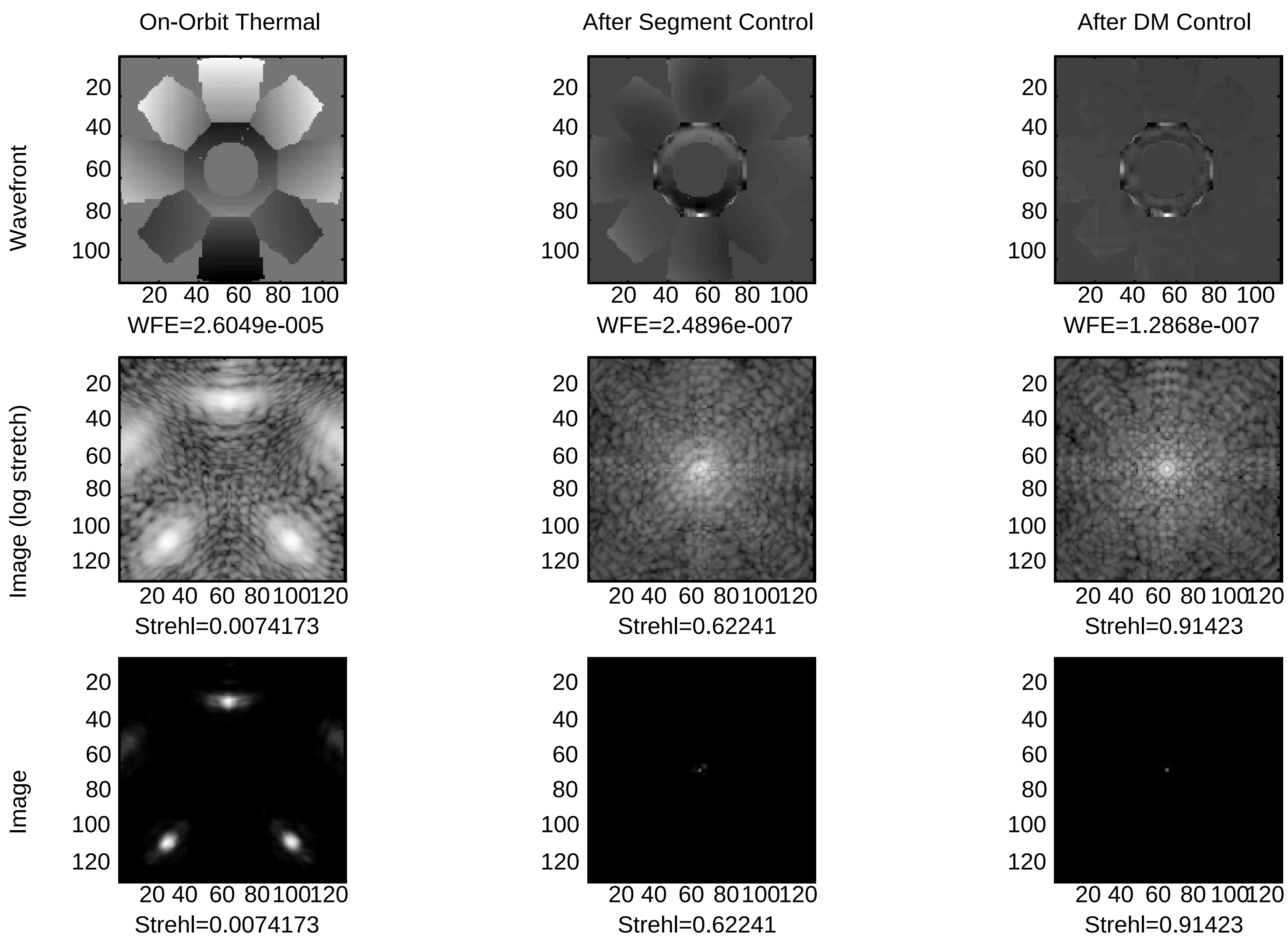
Wavefront Sensing And Control



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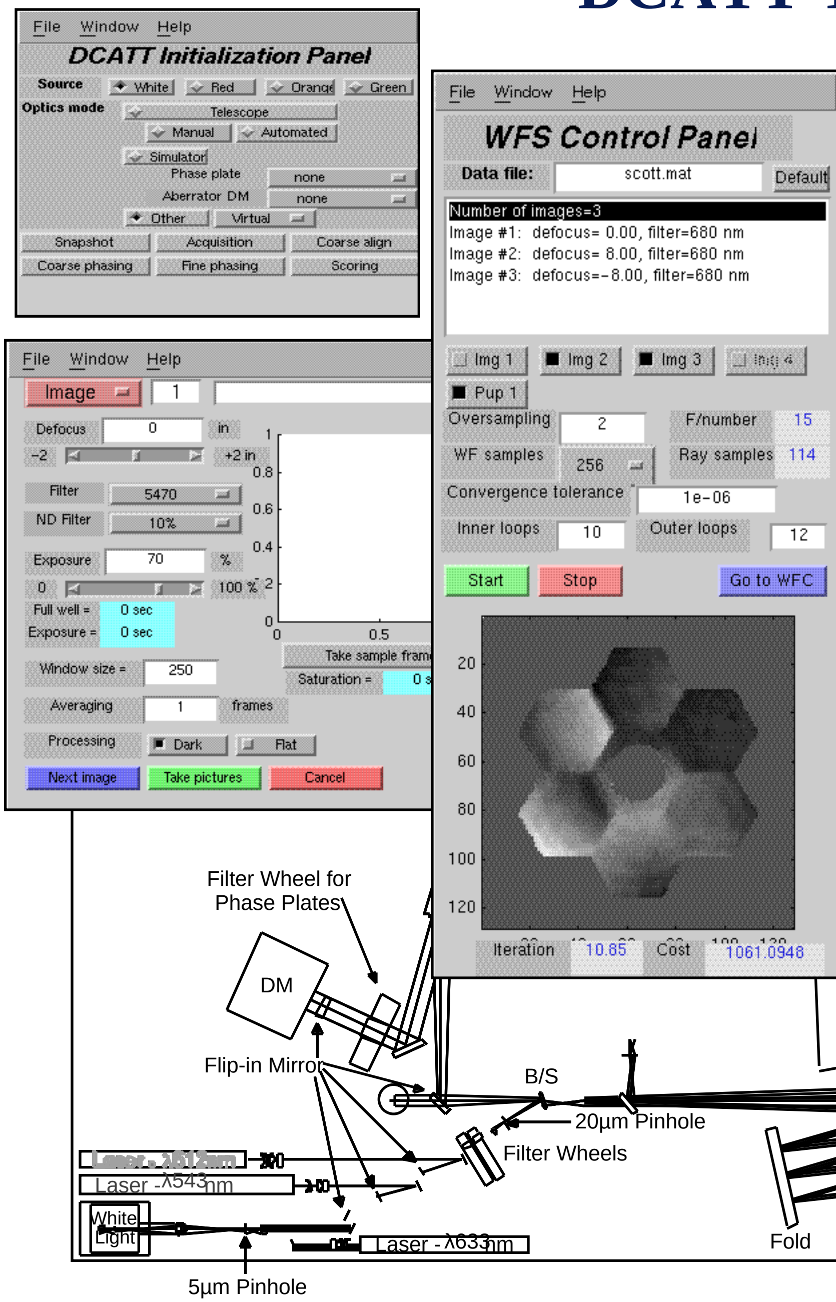
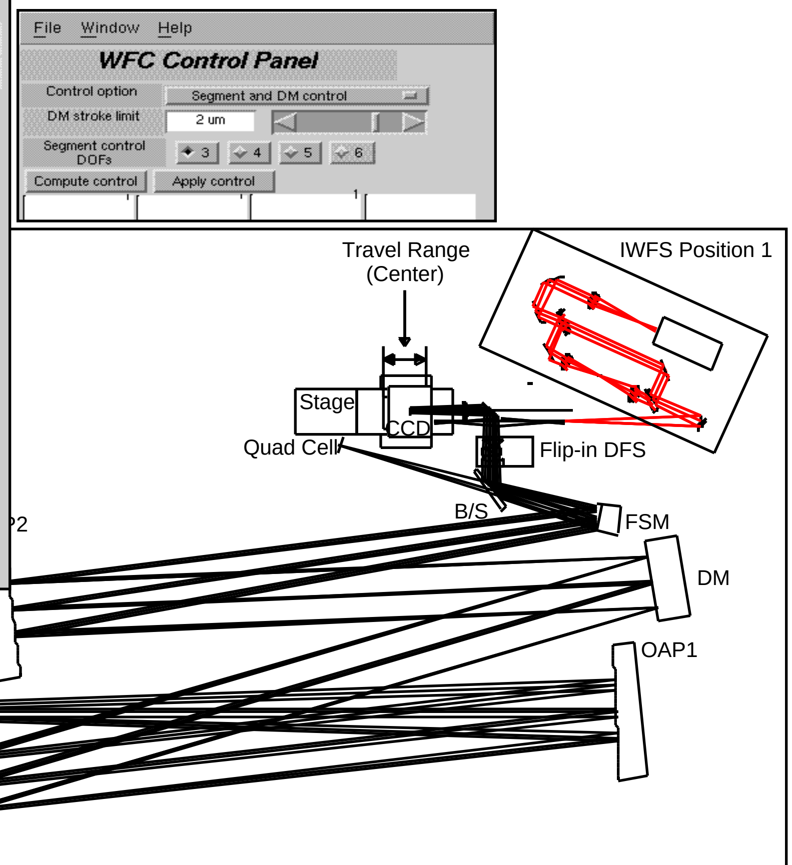
DCATT Testbed

- Control software prototyping
- Model validation
- WF control performance verification





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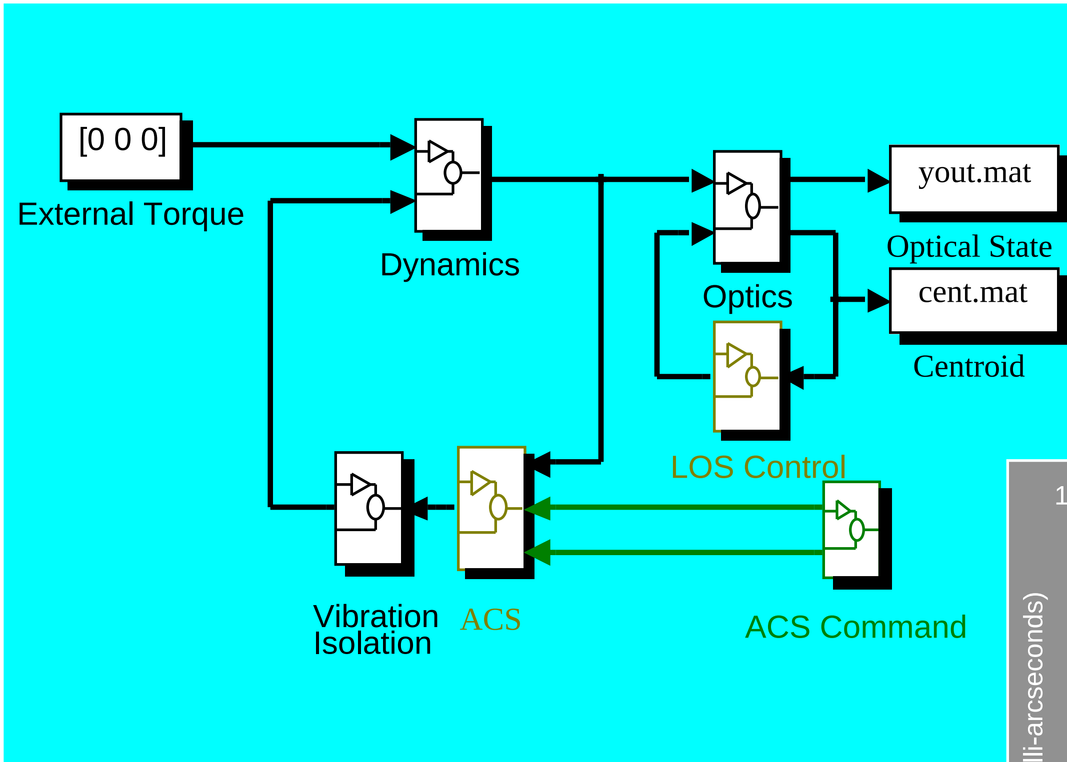
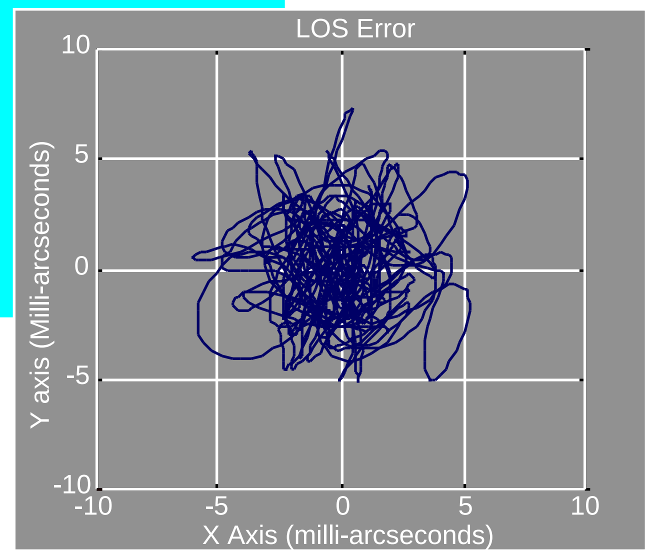
Rapid Protoyping via Simulation

Pointing Control Analysis



The top-level blocks shown in this diagram mask a complex hierarchical model with many layers comprising a simulation that includes vehicle attitude control, flexible body dynamics, vibration isolation and image stabilization control, and optics



Modern, object-oriented, graphical programming environment enables rapid prototyping of high-fidelity simulations that can answer "what-if" questions and quickly cover vast parametric trade spaces

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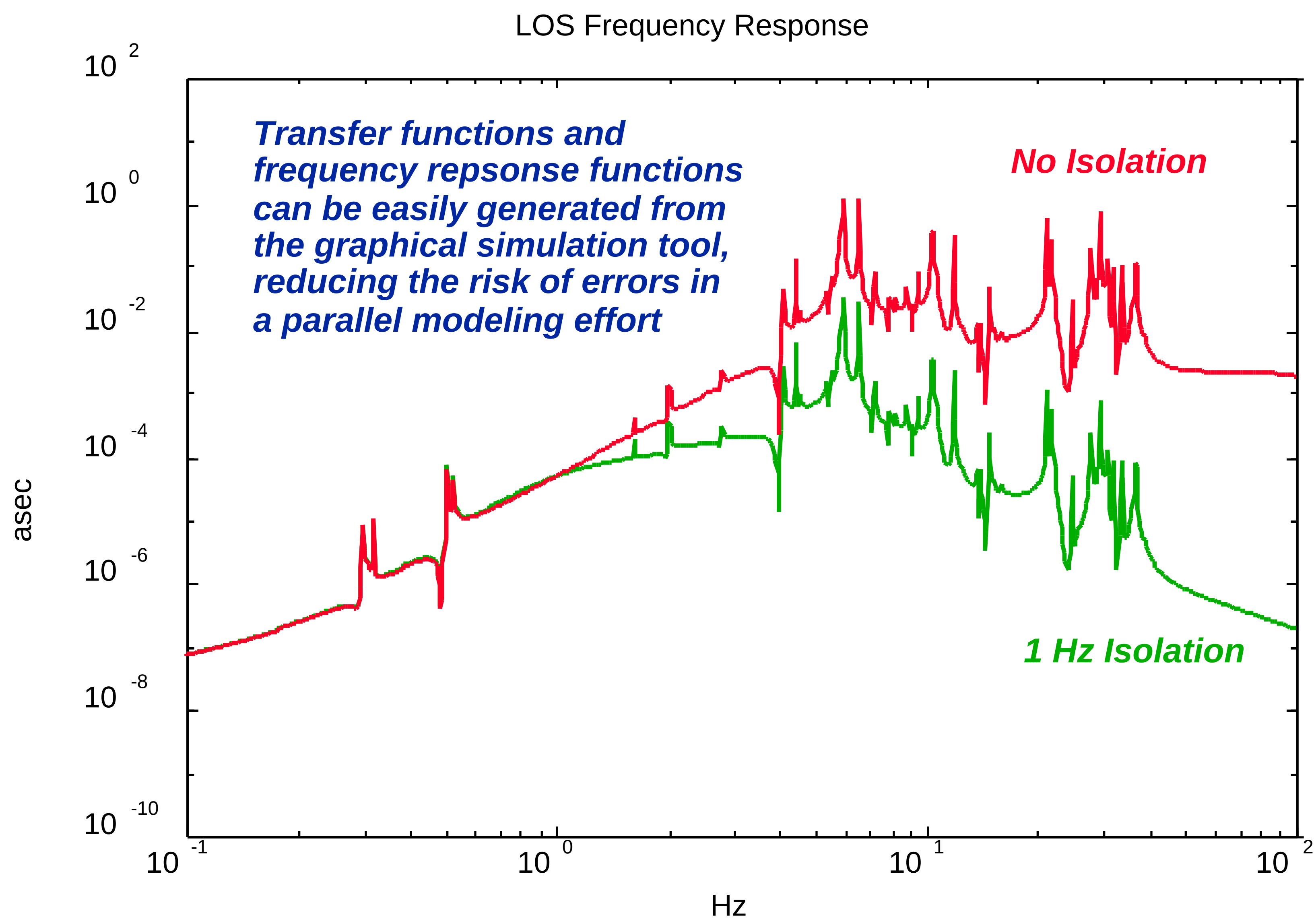
Linear Dynamics Analysis



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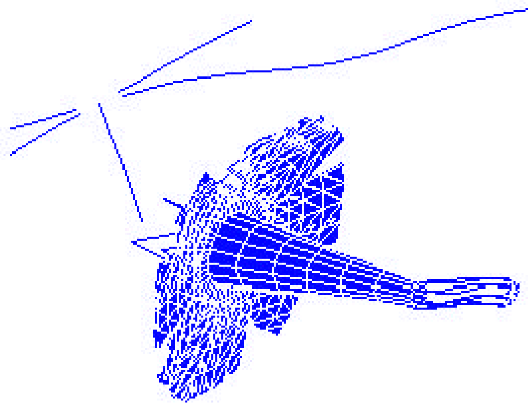
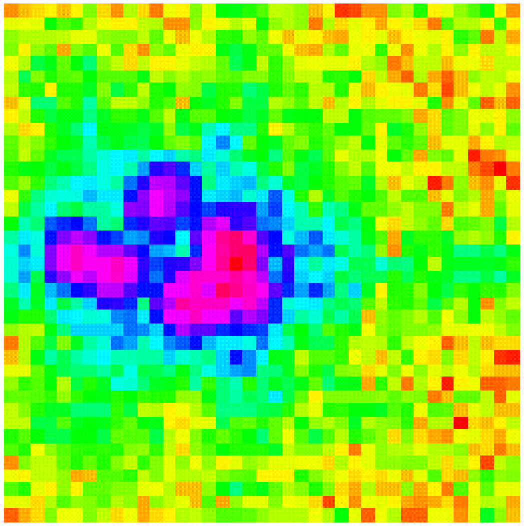
Optomechanical Analysis

Deformed FEM

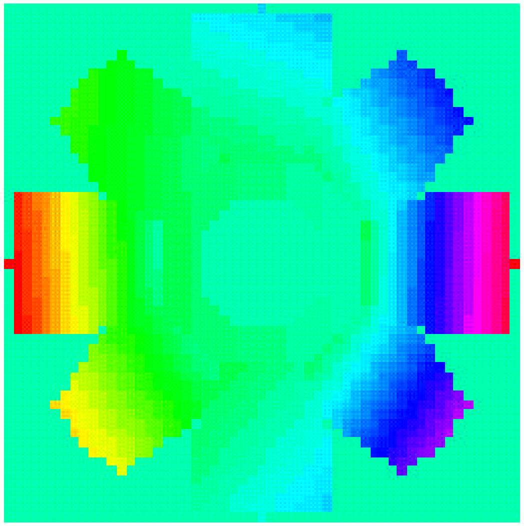


Structural dynamics (mode shapes) and the associated optical distortions are displayed as animations for qualitative analysis

Image (log stretch)



Wavefront Error



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INTEGRATED SYSTEMS MODELING

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Goddard Space Flight Center

David Redding
Jet Propulsion Laboratory, California Institute of Technology

January 14, 1998

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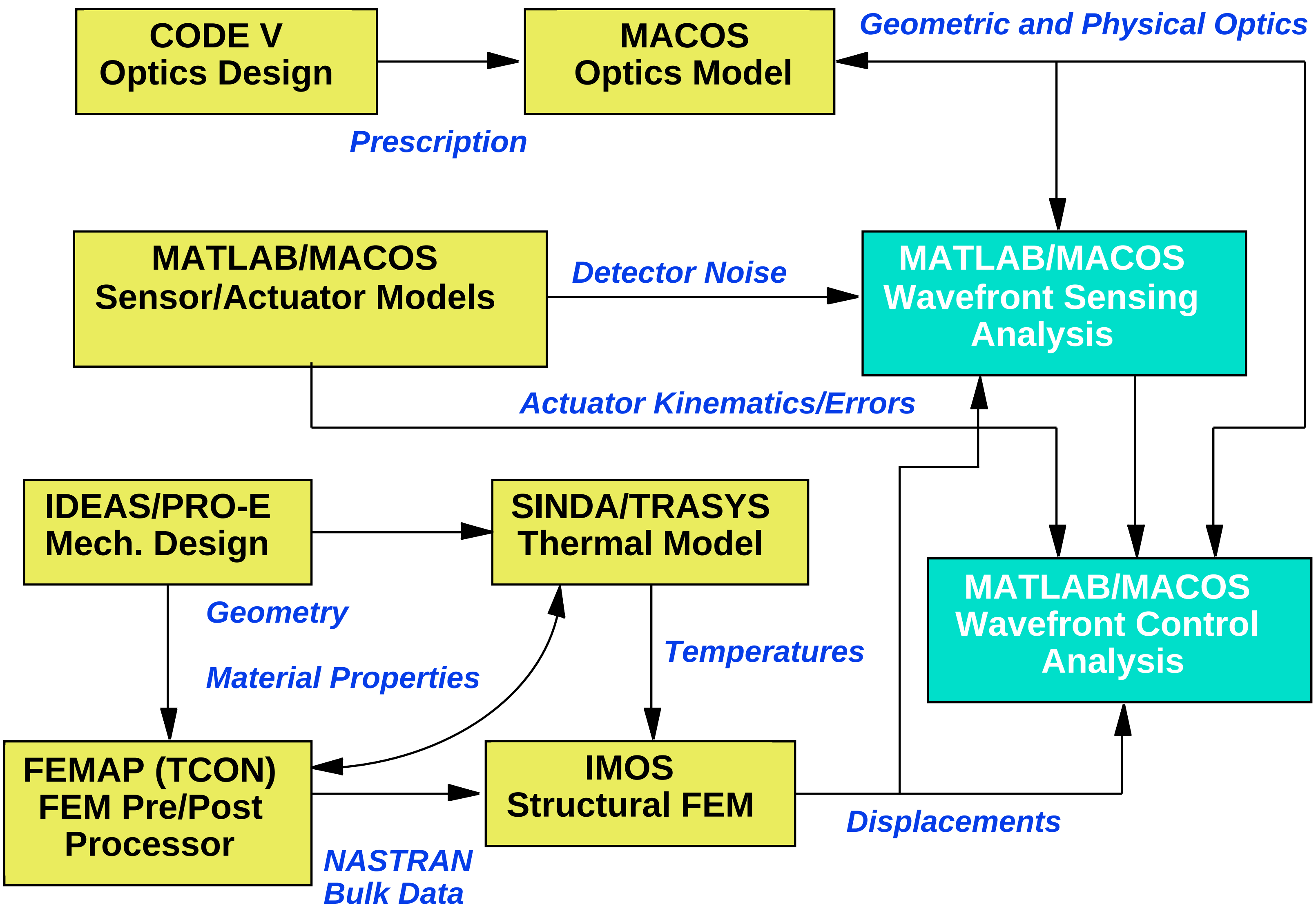
Integrated Modeling Flow - Static Analysis



Next
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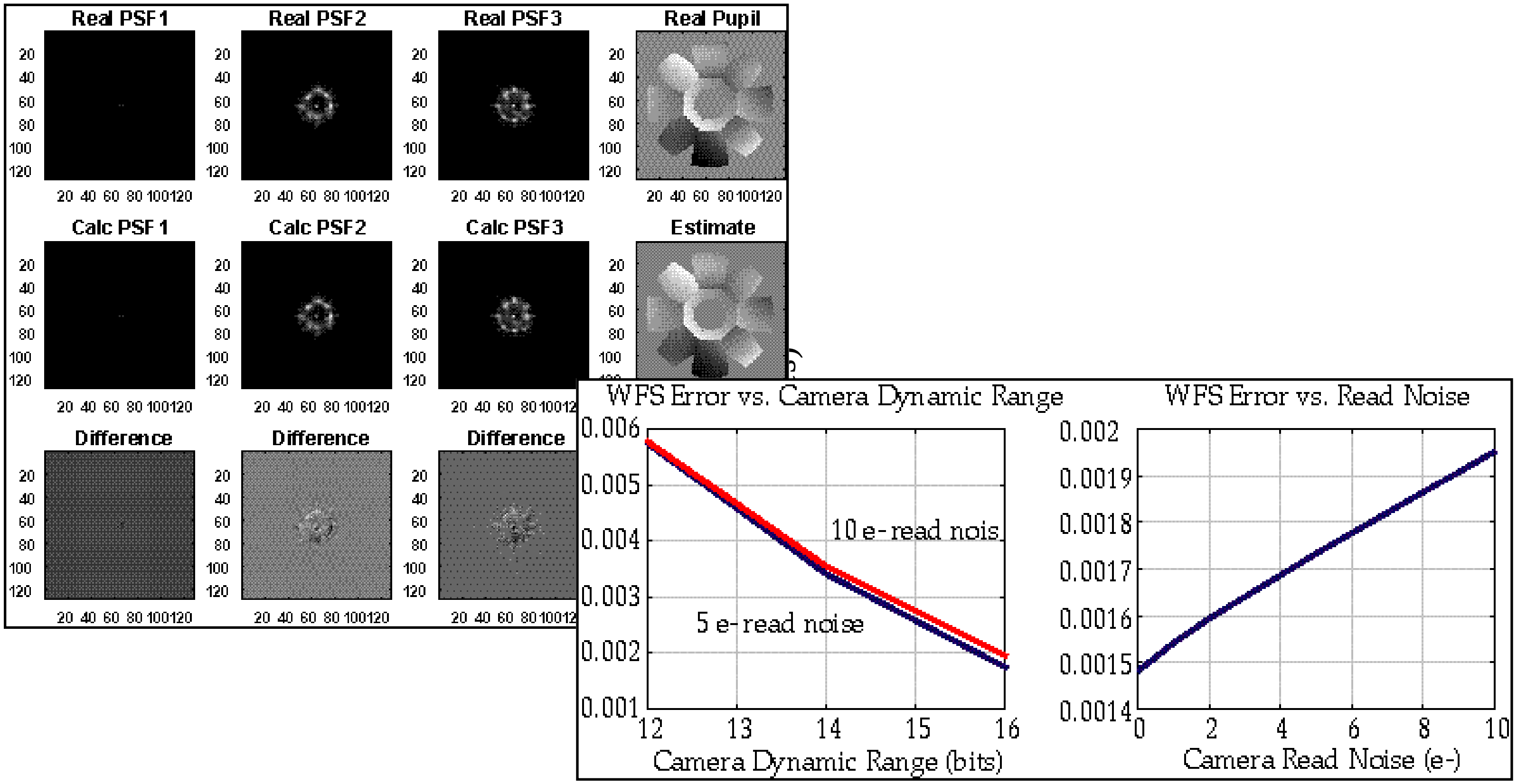
Wavefront Sensing Performance



- Ongoing performance studies at JPL and GSFC address WF control performance
- Noise sources: shot noise, read noise, stray and scattered light, crosstalk, finite bandpass, jitter, background, resolved object, ...
- Algorithms: phase retrieval (several), phase diversity, phase unwrapping, ...
- Sensors: Science camera, dispersed-fringe sensor, interferometric WFS, ...
- Computing: workstation, supercomputer, on-board supercomputer
- Control: actuator errors, DM, PM bending, stroke-vs-density, ...
- Validation: DCATT testbed

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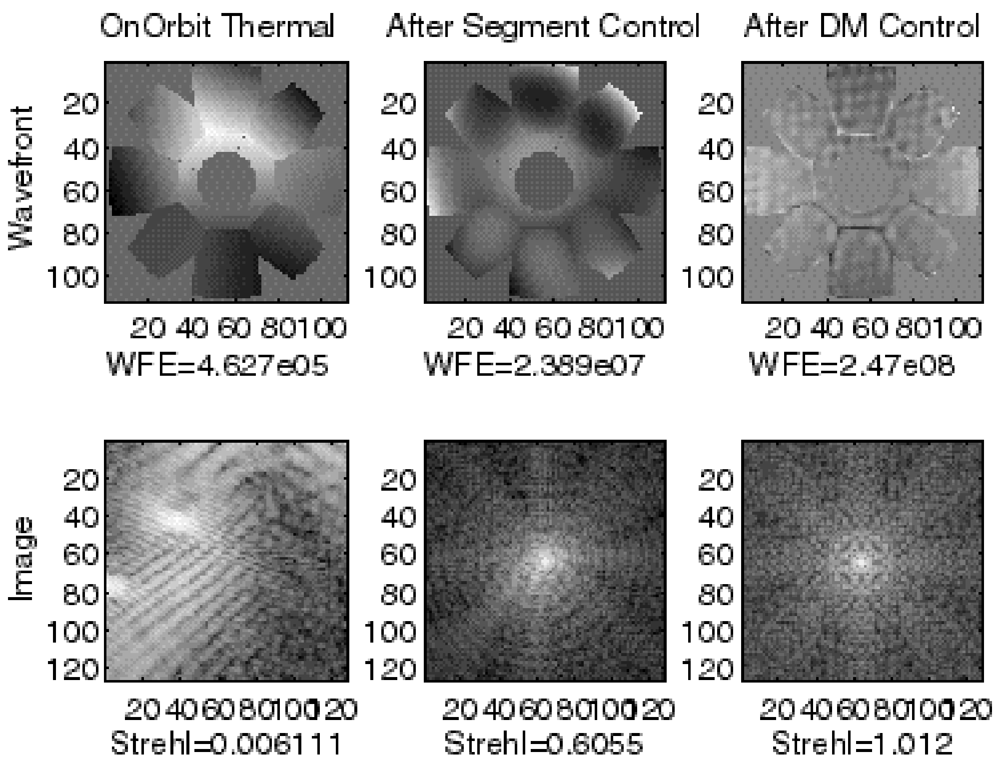
Ground-to-Orbit Thermal Response: All-Be OTA



Beryllium OTA
Beryllium facesheet
Beryllium SM tower
FEM version 12/97

"Cold-figured" telescope
Telescope perfect at T = 100°K

On-orbit T = 30 - 63 °K

Be CTE = 0.5 ppm
(integrated 100°K to 30°K)
Ti segment actuator CTE = 6 ppm

Wavelength = 2 um
Segment control in tip/tilt/piston DOFs only

- **"Cold figured" OTA: perfect at 100°K, deforms when cooled to operational temperature**
  - **Isotropic materials**
- **Compensated with 3DOF segment control, 349 DM actuator control**
- **Improvements can be made to meet goal of 100 nm WFE post-segment control**
  - **6 DOF segment control**
  - **Improved cryo figuring**

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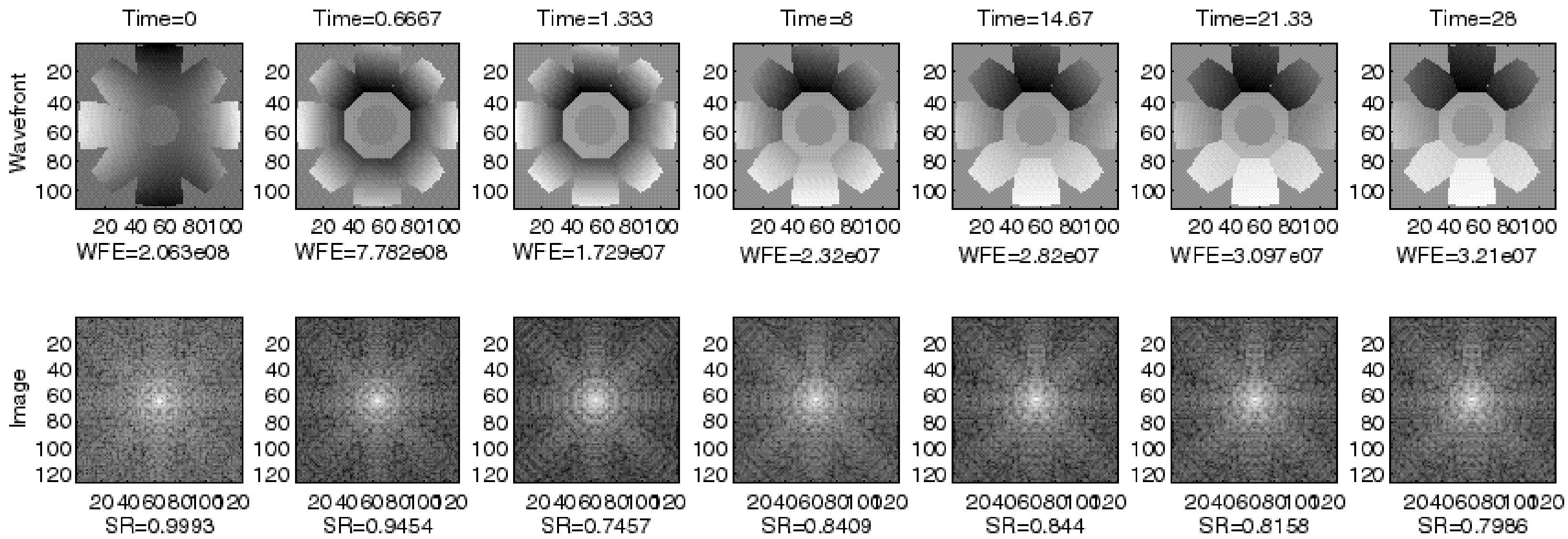
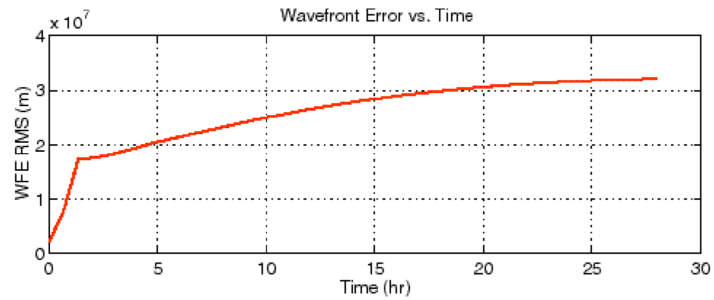
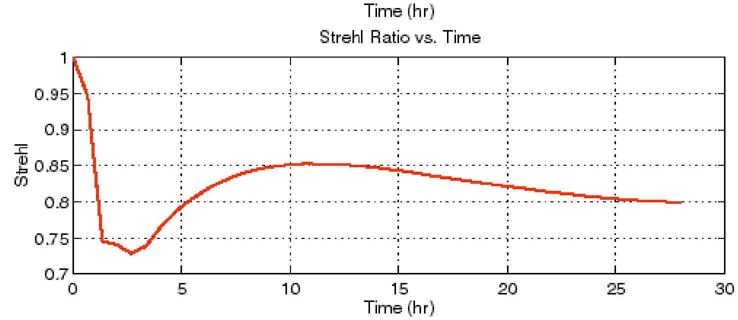
Thermal Transient Response: Be on Be



- Worst-case on-orbit thermal transient
  - Initialized at hottest attitude
  - 1 hr slew to cold extreme
  - 27 hour settle
- Performance near goal
- Improvement possible
  - Operational restrictions
  - Temperature sensing/open-loop control





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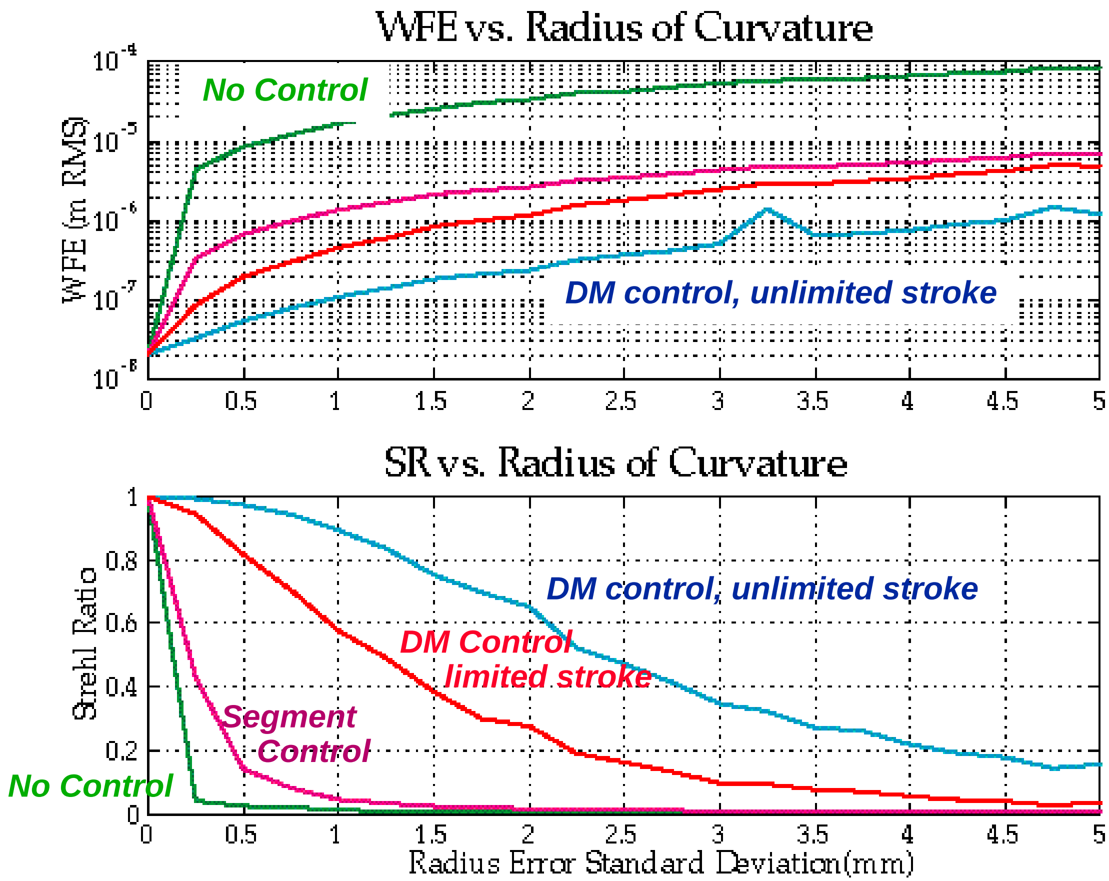
Segment Radius-of-Curvature Tolerances



Monte Carlo Simulation
Each segmrnt radius varied independently
100 trials per point
Wavelength = 2 um
DM stroke limit = ±2.5 um
3 DOF segment control only

- **Segment control only errors reach diffraction limit at 0.1 mm radius error standard deviation**
- **Stroke-limited DM reaches diffraction limit at 0.5 mm radius error standard deviation**

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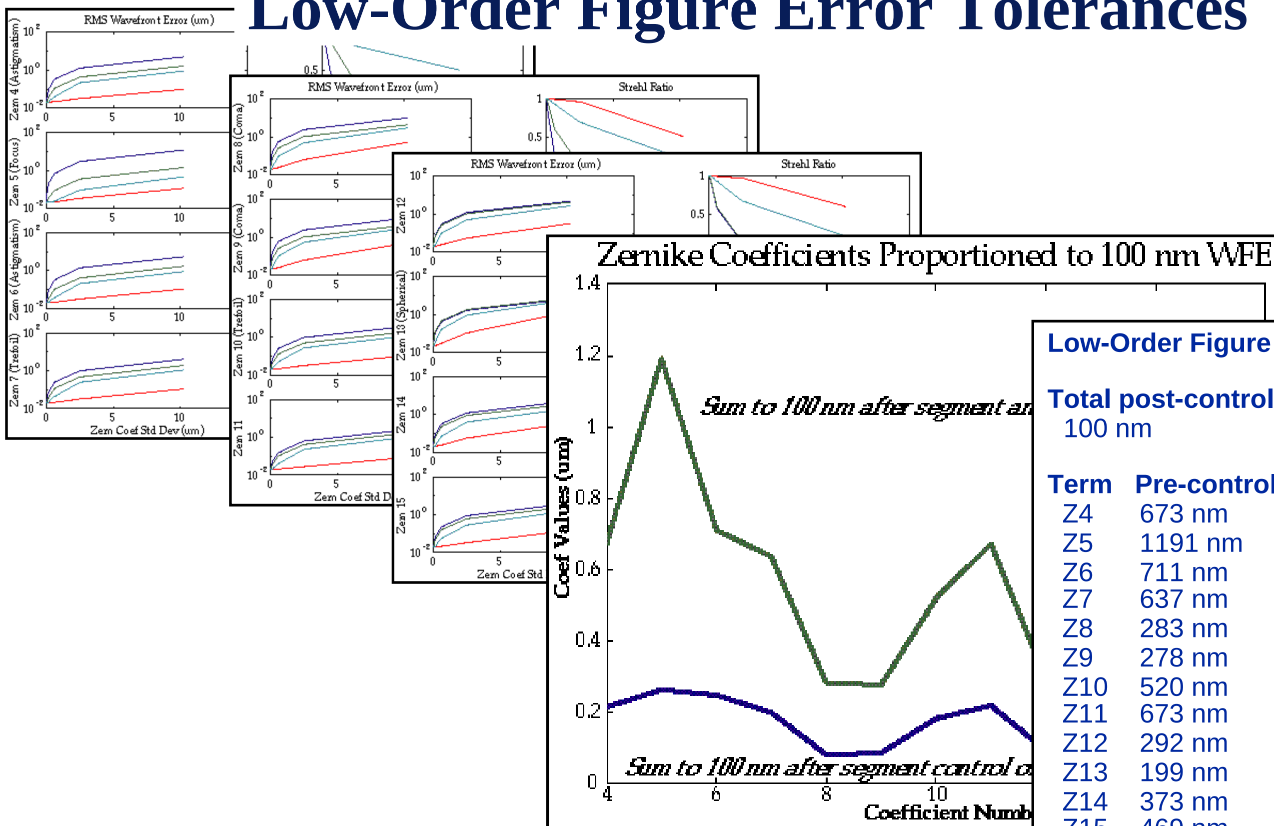
Low-Order Figure Error Tolerances



Low-Order Figure Error Budget

Total post-control WFE
100 nm

Term	Pre-control	Post-control
Z4	673 nm	43 nm
Z5	1191 nm	43 nm
Z6	711 nm	43 nm
Z7	637 nm	43 nm
Z8	283 nm	43 nm
Z9	278 nm	43 nm
Z10	520 nm	43 nm
Z11	673 nm	43 nm
Z12	292 nm	43 nm
Z13	199 nm	43 nm
Z14	373 nm	43 nm
Z15	469 nm	43 nm

- **Monte Carlo analysis conducted for each of the third-order Zernike polynomials**
  - **Zernikes varied independently on each segment**
  - **Zernikes normalized on the full NGST pupil, centered at PM vertex**
  - **100 runs per point, 12,000 runs total**
- **Monte Carlo results processed to find value for each Zernike coefficient that yields 43 nm WFE post WF control (includes 20 nm nominal WFE)**
  - **Cumulative effect sums to 100 nm WFE**

NGST

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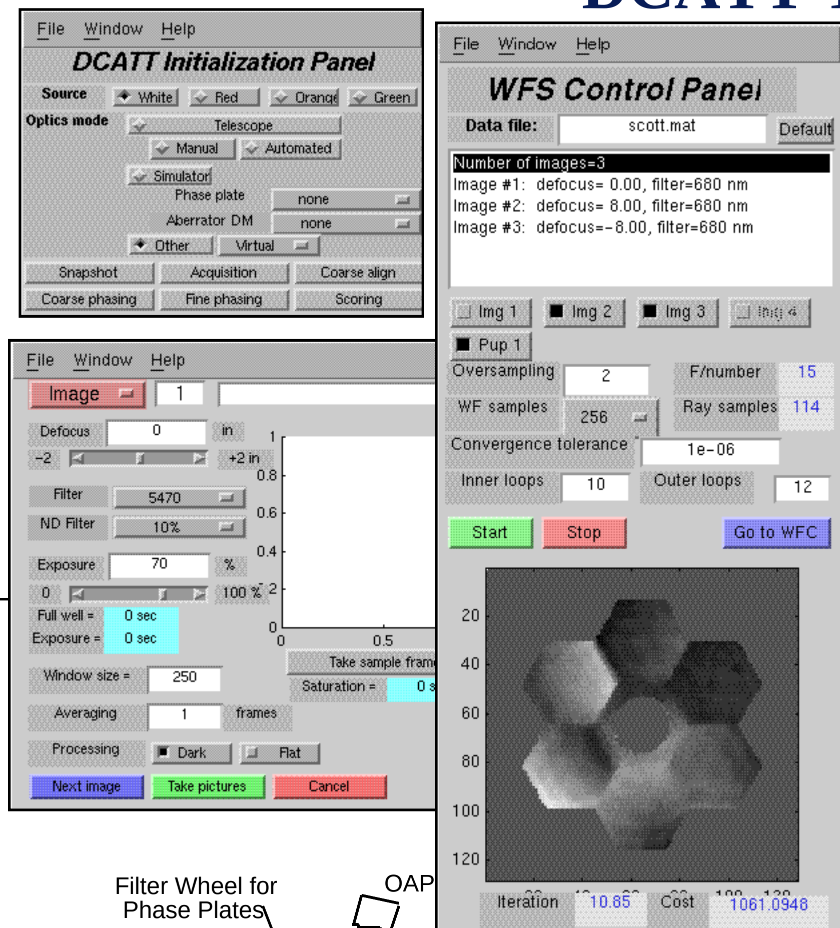
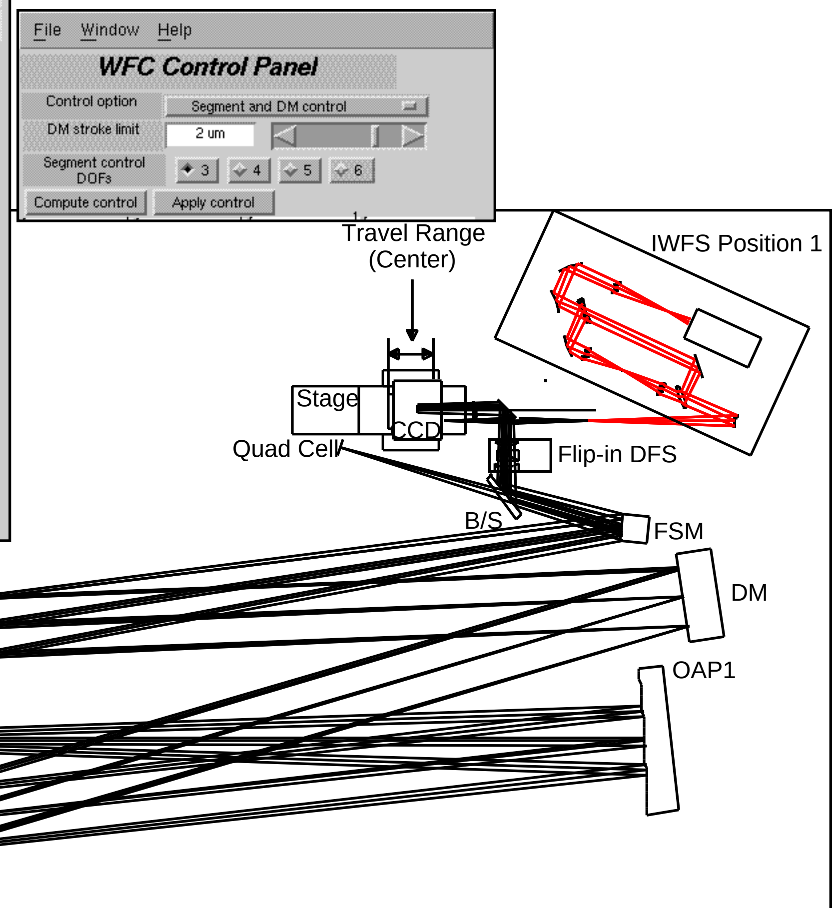
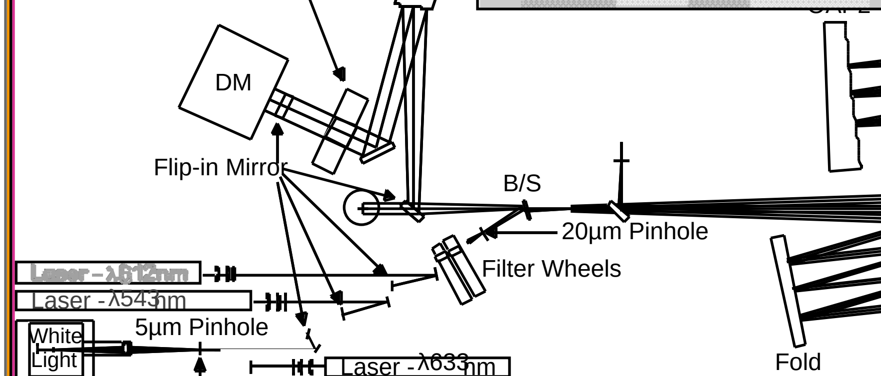
DCATT Testbed



- WF sensing and control performance verification
- Control software prototyping
- Model validation





Technology Program Overview

Presentation to the NGST Standing Review Board

Dr. Daniel R. Coulter

NGST Project Technologist and

Technology & Validation IPT Lead

January 14, 1998

Next Generation Space Telescope

Outline

- The NGST Challenge and What We Plan to do Differently
- Technology Program Goals
- Program Approach
- Planning Process
- Organizational Structure
- Program Plan
  - Technology Products
  - Testbeds
  - Flight Experiments
- Technology Roadmap, Schedule and Budget

The NGST Challenge

- The NGST challenge is to build a telescope system with:
  - up to 10 times the collecting area of HST,
  - < 25% the mass, and
  - < 25%the life cycle cost.

- Several existing concepts appear to meet the science and cost goals established for NGST by NASA.
  - The viability of these concepts depends on substantial extensions of current technology in certain areas.

- A well planned, timely, adequately funded technology development and validation program that enables laboratory innovations to proceed to flight readiness is required to provide key technology and to demonstrate readiness to do NGST within the programmatic, cost and schedule constraints.

Accepting the Challenge!

- We are laying out a new course for technology driven NASA missions.
  - *Complete success is not assured, BUT, following the old paths will lead to failure!*

- Simply invoking the promise of "New Technology" is not good enough either! The conventional wisdom says:

  New Technology = Risk = Performance, Cost, Schedule Hits

- Numerous examples support the conventional wisdom, but why?
  - *Because projects enter Phase C/D with a poor understanding of their technology and immature, unproven technology on the critical path!*

- So, what do we have to do differently to succeed?
  - *Provide new technology AND*
  - *New processes for adequate development, validation and "transfer" of key technology to the mission implementors.*

What Are We Doing Differently?

- Planning and executing a ≥ $160M program to develop key technologies and multiple technology options prior to the start of Phase C/D.
- Emphasizing validation of technological solutions through:
  - extensive testing of technology products
  - development and operation of ground testbeds
  - executing relevant flight experiments
  - correlating experimental results with integrated model predictions
- Minimizing the need for "technology transfer" by cultivating technology suppliers (industry, academia, international partners, etc.) who the NGST flight system contractor can draw on to implement NGST

  <u>RATHER THAN</u>

  Developing all the key technology at the NASA labs which may or may not be effectively transferred to the flight system implementers.

- *<u>WE WILL "PROCEED TO PHASE C/D WHEN WE ARE READY"- Huntress</u>*

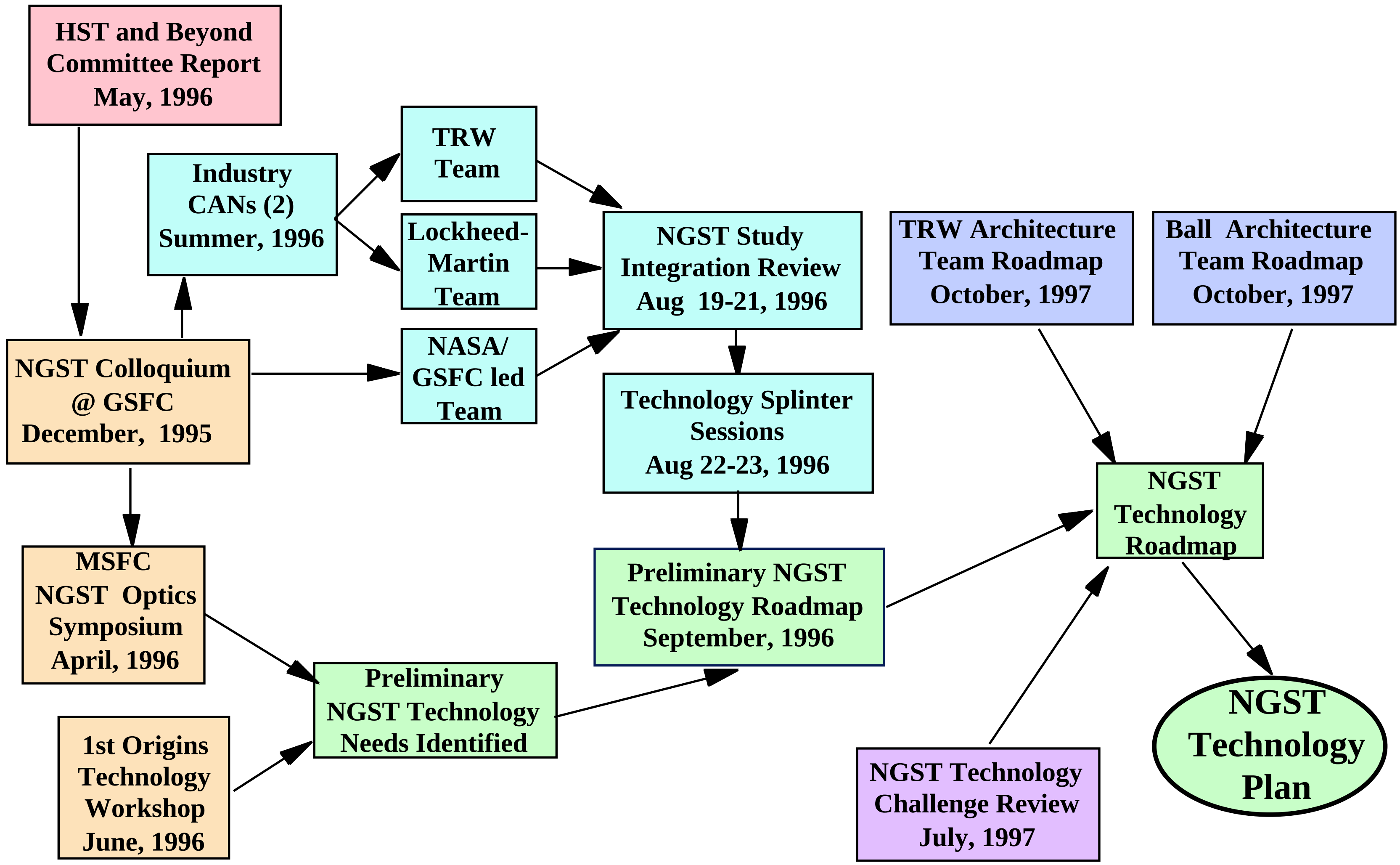
Technology Program Goals

- Retire as much technical, cost and schedule risk to the NGST flight systems as possible within programmatic constraints.
- Support the NGST Study by providing and examining technological options, generating test data on specific technology products and validating integrated models.
- Provide an adequate base of <u>validated</u> technology products to enable a high science value NGST Mission to be designed, built, launched and operated early in the next century.
- Provide an adequate group of technology suppliers and, where possible, multiple technology options for utilization by the NGST flight system contractor.
- Demonstrate, in concert with other elements of the NGST program, technical and programmatic readiness to do the NGST Mission in a timely and cost effective manner.
- Provide technological solutions which will help enable, not only NGST, but future large space optical systems including the Terrestrial Planet Finder and planet imager missions.

NGST Technology Development Approach

- Utilize a broadbased, open and continuous process for identifying, prioritizing and assessing key technology needs and opportunities
- Develop products and relevant test data rather than paper studies
- Validate technology products in ground based testbeds (e.g., DCATT and Flight System Testbed) and relevant flight experiments (Pathfinders 1,2,3)
- Compare experimental results to integrated model predictions and support Systems IPT in refining models as appropriate
- Develop a set of “fall back” solutions in the event baseline technologies are not successfully developed (e.g. monolith vs. segmented deployable)
- Cultivate the best technology suppliers through a series of open, competitive selection processes
- Balance NASA directed and industry directed technology development to keep NASA a “smart buyer” and to limit premature teaming while enabling the potential system contractors to develop their concepts
- Take maximum advantage of other technology developer’s efforts (other NASA missions, government labs, industry, academia, international space agencies, etc.) and form partnerships when possible
- Hold regular, open workshops and reviews

The Road to the NGST Technology Development Plan



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Technology Products Recommended for Development by Technology Splinter Sessions

SPLINTER GROUP/TECHNOLOGY NEED	PRIORITY
Optical Telescope Assembly Splinter	
· **Ultra-lightweight cryogenic mirrors**	1
· **Cryogenic actuators**	1
· **Cryogenic deformable mirror**	1
· **Deployable structures**	2
· **Wavefront sensing & optical control**	2
Science Instrument Module Splinter	
· **Low noise, large format near IR & thermal IR detectors**	1
· **Vibrationless cryo-coolers**	2
· Digital micro-mirror array	3
Spacecraft Splinter	
· **Inflatable or deployable sunshade**	1
· **Vibration isolation**	1
· ***Low temperature materials property characterization***	2
· Advanced startracker	3
Operations Splinter	
· ***Flight software development methodology***	1
· **Autonomous scheduling and execution**	1
· **User interaction tools**	2
· Autonomous fault management	3
· Control executive	3
· Data compression	3
Systems Splinter	
· ***Integrated modeling tools***	1
· ***System simulator***	1

Red = explicitly included in existing Technology Development Program

Italics = addressed somewhere in NGST plan

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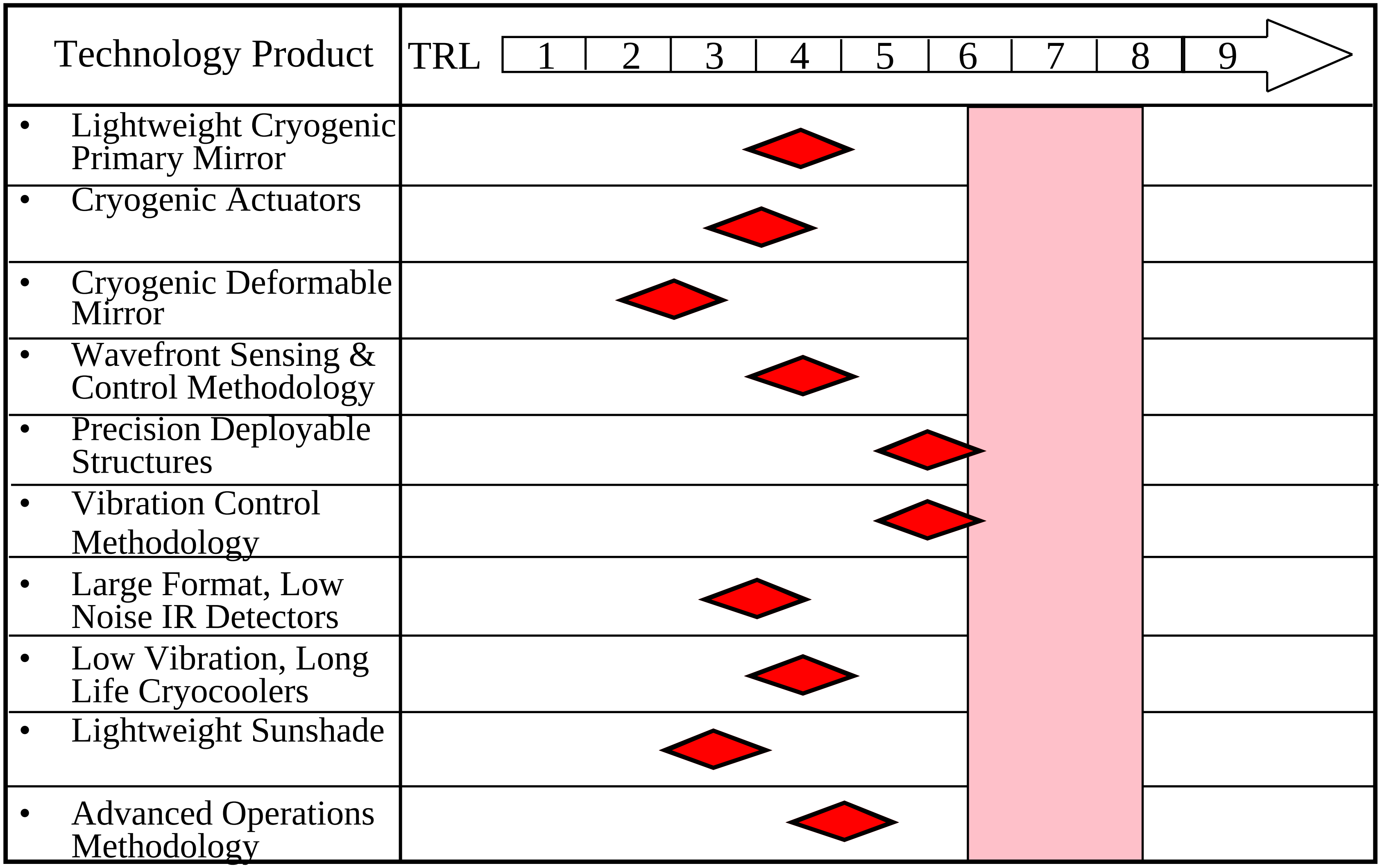
NASA Technology Readiness Levels (TRLs)

- **Level 1** Basic principles observed and reported
- **Level 2** Technology concept and/or application formulated
- **Level 3** Analytical & experimental critical function and/or characteristic proof-of-concept demonstrated
- **Level 4** Component and/or breadboard validation in laboratory
- **Level 5** Component and/or breadboard validation in relevant environment
- **Level 6** System/subsystem model or prototype demonstrated in a relevant environment (ground or space)
- **Level 7** System prototype demonstrated in a space environment
- **Level 8** Actual flight completed and “flight qualified” through test and demonstration (ground or space)
- **Level 9** Actual system “flight proven” through successful mission operations

NGST Key Technology Product Maturity Assessment



= Current TRL (1/98)

= TRL required to move to Phase C/D/E

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NGST Technology & Validation IPT Organization

- Technology & Validation IPT
  D. Coulter (lead), JPL
  L. Pacini (deputy), GSFC
  - Pathfinder Validation Flights
    L. Pacini, GSFC
    - Pathfinder 1&2: ISIS
      L. Pacini, GSFC
      M. Lou, JPL
    - Pathfinder 3: NEXUS
      L. Pacini, GSFC
      D. Coulter, JPL
  - Industry Directed Technology
    D. Coulter, JPL
    - TRW
      C. Lillie, TRW
    - Ball Aerospace
      W. Meyer, Ball Aerospace
  - Optics Technology
    J. Bilbro, MSFC
    - Lightweight Mirrors
      J. Bilbro, MSFC
      - Composite Optics
      - Univeristy of Arizona
      - Other
    - Cryo Actuators
      G. Horner, LaRC
      - Cryo Actuator Testing
        R. Chave, JPL
    - Cryo Deformable Mirrors
      J. Bilbro, MSFC
    - Large Aperture Space Telescope SBIRs
      J. Bilbro, MSFC
      D. Coulter, JPL
  - Detector Technology
    C. McCreight, ARC
    - InSb Arrays
      University of Rochester & SBRC
    - IBC Arrays
      ARC, SBRC & Cornell University
    - HgCdTe Arrays
      University of Rochester & Rockwell
  - Spacecraft Technology
    D. Coulter, JPL
    - Lightweight Sunshade
      M. Lou, JPL
      (not NGST funded)
    - Low Vibration Cryocoolers
      S. Castles, GSFC
      (not NGST funded)
      - Sorption Cooler
        L. Wade, JPL
        (not NGST Funded)
    - Vibration Control
      J. Spanos, JPL
      (not NGST funded)
  - DCATT
    C. LeBoeuf, GSFC
    - Testbed Development and Operations
      C. LeBoeuf, GSFC
    - Wavefront Sensing & Control
      D. Redding, JPL
    - Stimulus
      D. Redding, JPL
  - Operations Technology
    K. Kalinowski, GSFC
    - Adaptive Scheduler
      TBD, GSFC
    - Scientist's Expert Assistant
      TBD, GSFC

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Current NGST Technology Product Development Efforts

- **Lightweight Cryogenic Primary Mirror- 2 Optics RFOs, advanced materials & fabrication technology, AXAF chamber modifications (MSFC); *Architecture Study contractors efforts***
- **Cryogenic Actuators- Actuator RFO (LaRC); actuator test facility (JPL)**
- **Cryogenic Deformable Mirror- SBIR Φ2 (XInetics, MSFC); Actuator RFO (LaRC); *Architecture Study contractors efforts***
- **Wavefront Sensing &Control Methodology- DCATT Testbed (GSFC, JPL, MSFC); *Architecture Study contractors efforts***
- **Precision Deployable Structures- *Architecture Study contractors efforts***
- **Vibration Control Methodology- Space Interferometry Mission; *Architecture Study contractors efforts***
- **Large Format, Low Noise IR Detectors- ORIGINS IR Detector NRA (ARC); NGST Detector RFO (ARC); *Architecture Study contractors efforts***
- **Low Vibration, Long Life Cryocoolers- NASA Crosscutting Technology Program (GSFC, JPL)**
- **Lightweight Sunshade- NASA Crosscutting Technology Program (JPL, GSFC)**
- **Advanced Operations Methodology- Operability IPT program (GSFC); NASA HPCC funded efforts at GSFC and STScI**

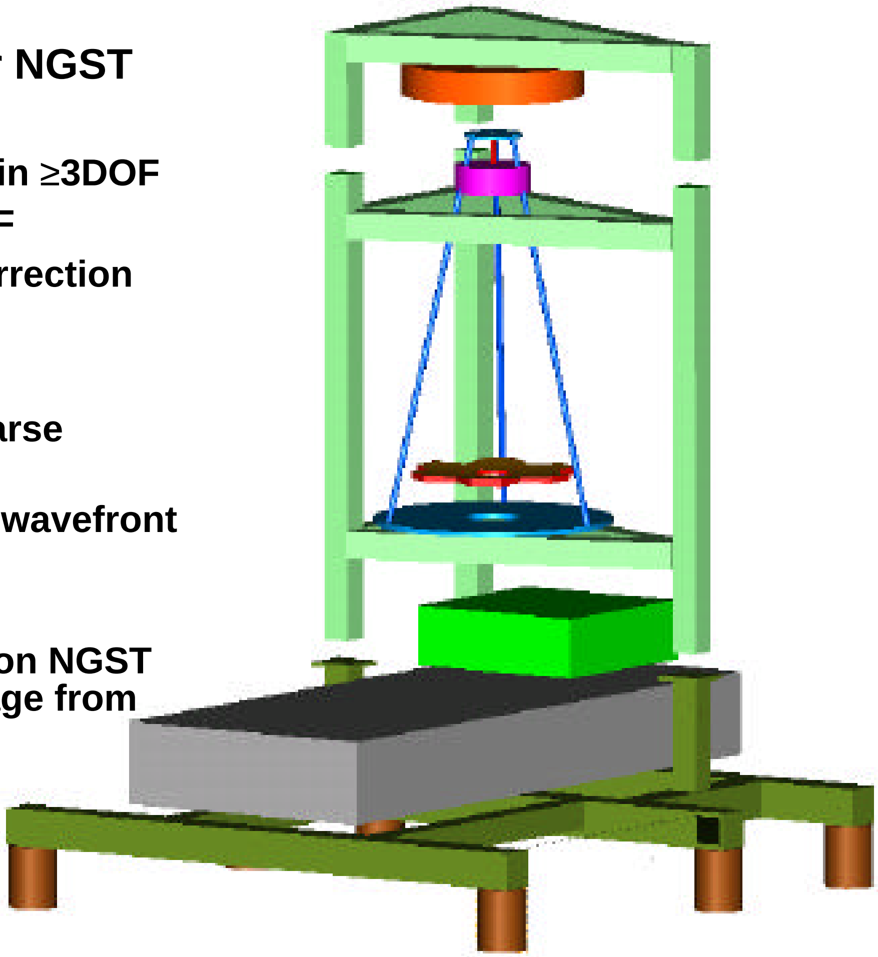
Selected NGST Technology Product Performance Goals

- **Lightweight Cryogenic Primary Mirror- 15kg/m^2, DL@2μm, T=30K, 2m diameter, compatible with multiple architectures**
- **Cryogenic Actuators- T= 30-300K, resolution ≤20nm, stroke = 0.5-10mm, mass = 20-50gm, power dissipation ≤0.5mwatts , zero hold power, position & force types**
- **Cryogenic Deformable Mirror- T≤30K, resolution ≤5nm, stroke =5μm, actuator spacing ≤1mm, # of actuators≈1000**
- **Wavefront Sensing &Control Methodology- image based wavefront sensing, alignment & phasing algorithms, 0.1-3 Hz image stabilization**
- **Precision Deployable Structures- primary mirror, secondary mirror, isolation truss, accuracy ≤25μm - 1mm, 10nm stability**
- **Vibration Control Methodology- passive damping, active isolation, ≥1 Hz**
- **Large Format, Low Noise IR Detectors- 4kx4k (NIR), 1kx1k(TIR), dark current=0.01-1e/sec, read noise ≤3-15e/sec**
- **Low Vibration, Long Life Cryocoolers- T=30K and 7K, cooling power ≤10 mwatts**
- **Lightweight Sunshade- deployable or inflatable, 10mx30m, enable telescope to cool to T<60K, low volume, mass ≤100kg, space durable**
- **Advanced Operations Methodology- Adaptive Scheduler, flight software tools, Expert Assistant (proposal preparation, observation planning)**

Next Generation Space Telescope

Developmental Cryogenic Active Telescope Testbed (DCATT)

- Optical Control System Testbed for NGST
  - ≈1m segmented primary mirror (Al)
  - primary mirror segments controlled in ≥3DOF
  - secondary mirror controlled in 5 DOF
  - deformable tertiary mirror for WF correction
  - fast mirror for image stabilization
  - image based WF sensing camera
    - dispersed fringe sensor for coarse alignment/phasing
    - phase diversity sensor for fine wavefront sensing
    - auxiliary Hartmann sensor
  - baseline control architecture based on NGST "Yardstick" concept- software heritage from Palomar AO System
  - Stimulus
    - laser source
    - phase plates
    - scoring interferometer



- Measurement in double pass with autocollimation flat
  - Phase 1: ambient operation with off the shelf components
  - Phase 2: telescope cold with selected "flight like" component upgrades
- Primary goals are validation of optical control architecture and integrated model predictions

NGST Technology Validation Matrix

X = **Primary validation tests**
x = Secondary or potential validation tests

NGST Technology Products \ NGST Technology Validation Test Facilities & Experiments	Primary Mirror Optical Test Facility	Dynamics Test Facility	Cryogenic Actuator Testbed Facilities	DCATT Testbed/Cryo Test Chamber	Industry Deployable Structures Testbeds	AF Phillips Res. Site UltraLITE Testbed	Space Interferometry Mission Testbed	IR Focal Plane Array Test Facilities	Cryocooler Test Facilities	Science Instrument Testbed	NGST Operations Testbed/Simulator	HPCC Program Testbed	NGST Flight System Testbed	Pathfinder 1&2 Flight Experiments (ISIS)	Pathfinder 3 Flight Experiment (NEXUS)	NGST Integrated Models
Lightweight Cryogenic Primary Mirror	X	X											x	x	X	X
Cryogenic Actuators	x		X	x									x	x	X	X
Cryogenic Deformable Mirror			X	x									x		X	X
Wavefront Sensing & Control Methodology				X									X		X	X
Precision Deployable Structures		X			X	x							X	x	X	X
Vibration Control Methodology					X	x	X								X	X
Large Format, Low Noise IR Arrays								X		X					X	
Low Vibration, Long Life Cryocoolers									X	X				x	X	
Lightweight Sunshade														X		X
Advanced Operations Methodology											X	x	X		X	x

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NGST Technology Product Validation

Technology Product	TRL 1 2 3 4 5 6 7 8 9
• Lightweight Primary Mirror	NMSD/ AMSD — NEXUS
• Cryogenic Actuators	SBIR — Actuator & DM RFO — NEXUS
• Cryogenic Deformable Mirror	SBIR — Actuator & DM RFO — DM Demo — NEXUS
• Wavefront Sensing/ Control Methodology	DCATT — NEXUS
• Precision Deployable Structures	Ind. Dir. Tech. — NEXUS
• Vibration Control	NASA/ Ind. — NEXUS
• Large Format, Low Noise IR Detectors	NASA IR Sensor NRA & NGST Technology Development — NGST SIM Testbed
• Low Vibration, Long Life Cryocoolers	NASA Cryocooler Tech. Program — NEXUS
• Lightweight Sunshade	NASA Inflatable Tech. Program — ISIS
• Advanced Operations Methodology	NGST Technology Development — NGST OPS Testbed

NGST

= Current TRL (1/98)

Next Generation Space Telescope

NGST Flight Experiments- Overview

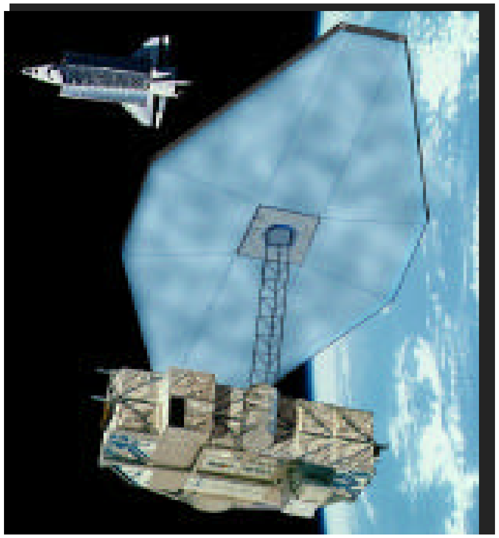
- A flight experiment program is a key part of the overall risk reduction strategy for NGST
- Even a simple space mission has substantial cost, complexity and risk
  - Justification requires obtaining significant results that are not practically achievable through ground tests
- The NGST Study team is looking primarily at flight testing on a major subsystem and system level
- Three 'Pathfinder' flight experiments (PF-1, PF-2, PF-3) were initially proposed
  - Currently, the plan is to combine the first two on a single flight to save cost
- Experiment definition, technology selection and management structure has not been completed
  - opportunities to reduce cost through partnering are being aggressively pursued with other US government agencies and international partners

Why Do Flight Experiments?

- Technical Rationale- Reduce technological risk to the flight system
  - validate key aspects of advanced (stretch) technology or system performance in space where ground tests are impractical
  - validate the performance of key subsystems and interfaces
  - validate integrated models and ground test results
  - demonstrate technological readiness to proceed to implementation phase (C/D/E) of NGST
- Programmatic Rationale- Reduce the programmatic risks to the mission
  - validate key aspects of the management & partnering approach
  - demonstrate the effectiveness of the NGST (industry/government) implementation team
  - demonstrate adequate understanding of the key system elements including cost and schedule
  - failure is not fatal; success demonstrates programmatic readiness to proceed to implementation phase (C/D/E) of NGST
- Sociological/Psychological Rationale- Get the stakeholders on board
  - eliminate the "giggle factor"
  - convince senior NASA Managers & Congress that we are ready to go

Pathfinder 1&2 Flight Experiments- ISIS

- Pathfinder 1- <u>Inflatable Sunshield In Space Experiment</u>
  - validates advanced (stretch) concept for an inflation deployed multilayer membrane sunshade (≈1/2 NGST scale)
  - STS deployed free-flyer; German ASTROSPAS S/C supplied at minimal cost to NGST
    - mid 2000 launch; ≈1 week duration; ≈$3M cost
  - four technical drivers
    - demonstrate controlled deployment
    - measure thermal performance of multilayer membrane shade
    - measure on-orbit dynamics of large shade
    - validate and refine structural & thermal models based on experimental data



ISIS

- Pathfinder 2- Small Attached Payloads Experiment
  - provide access to space for technology developers
  - utilize excess space, mass, power and data storage beyond that required for ISIS to support small experiments
  - validate component/subsystem performance in space- payloads provided by experimenters
  - ≤$300K total cost to NGST

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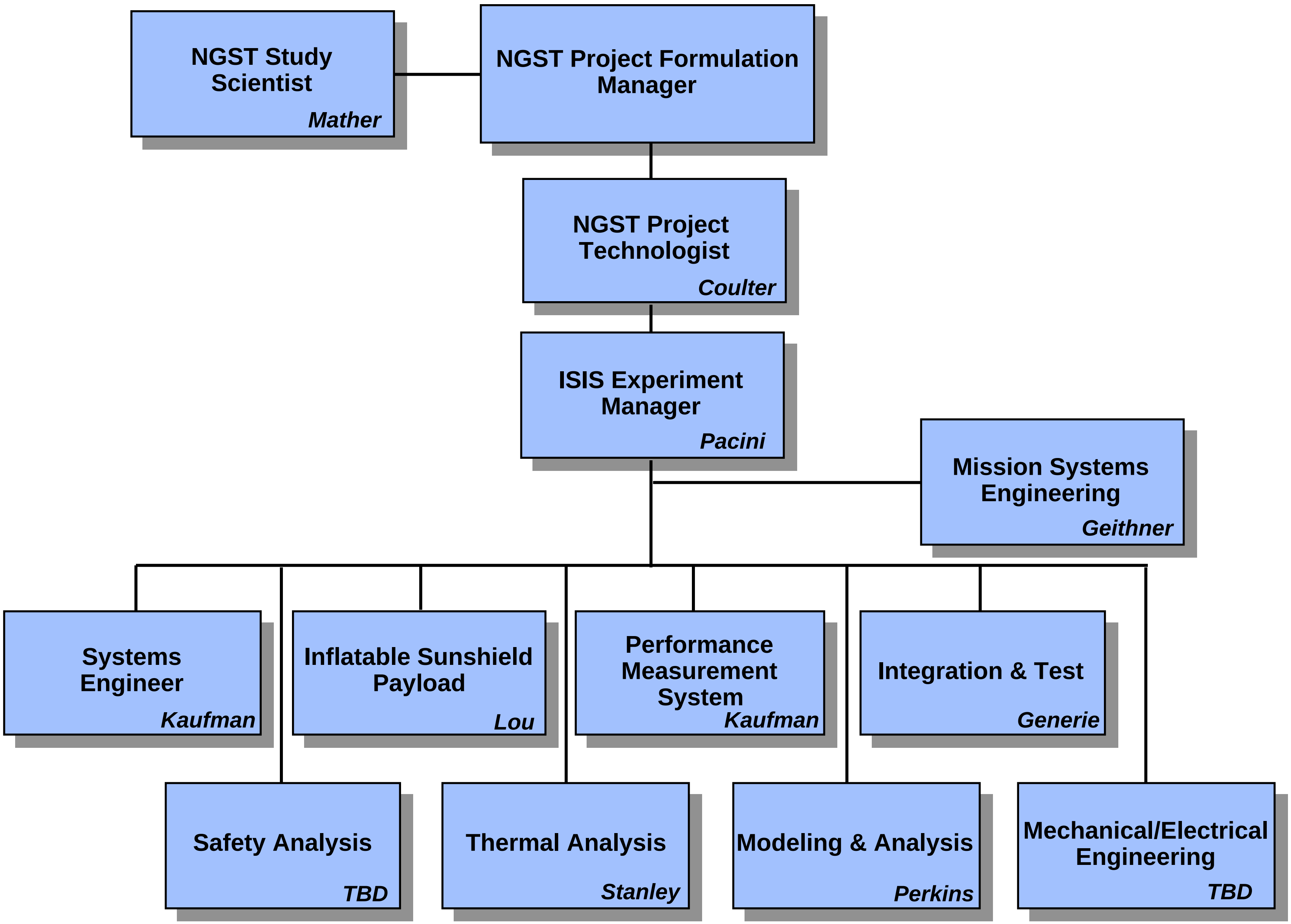
ISIS Team



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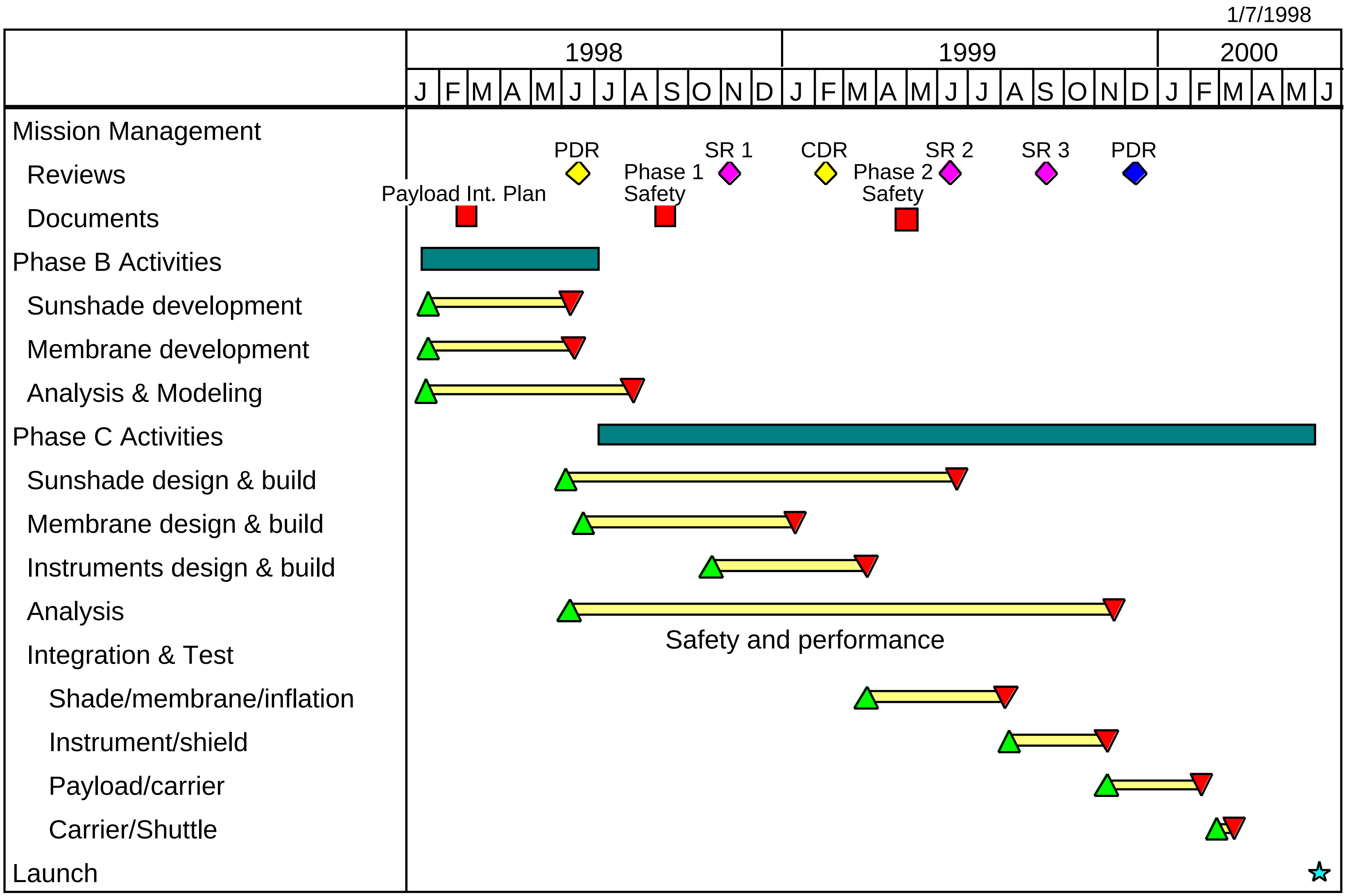
ISIS Schedule



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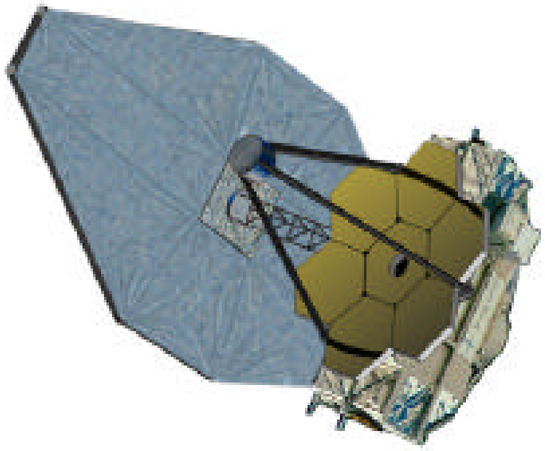
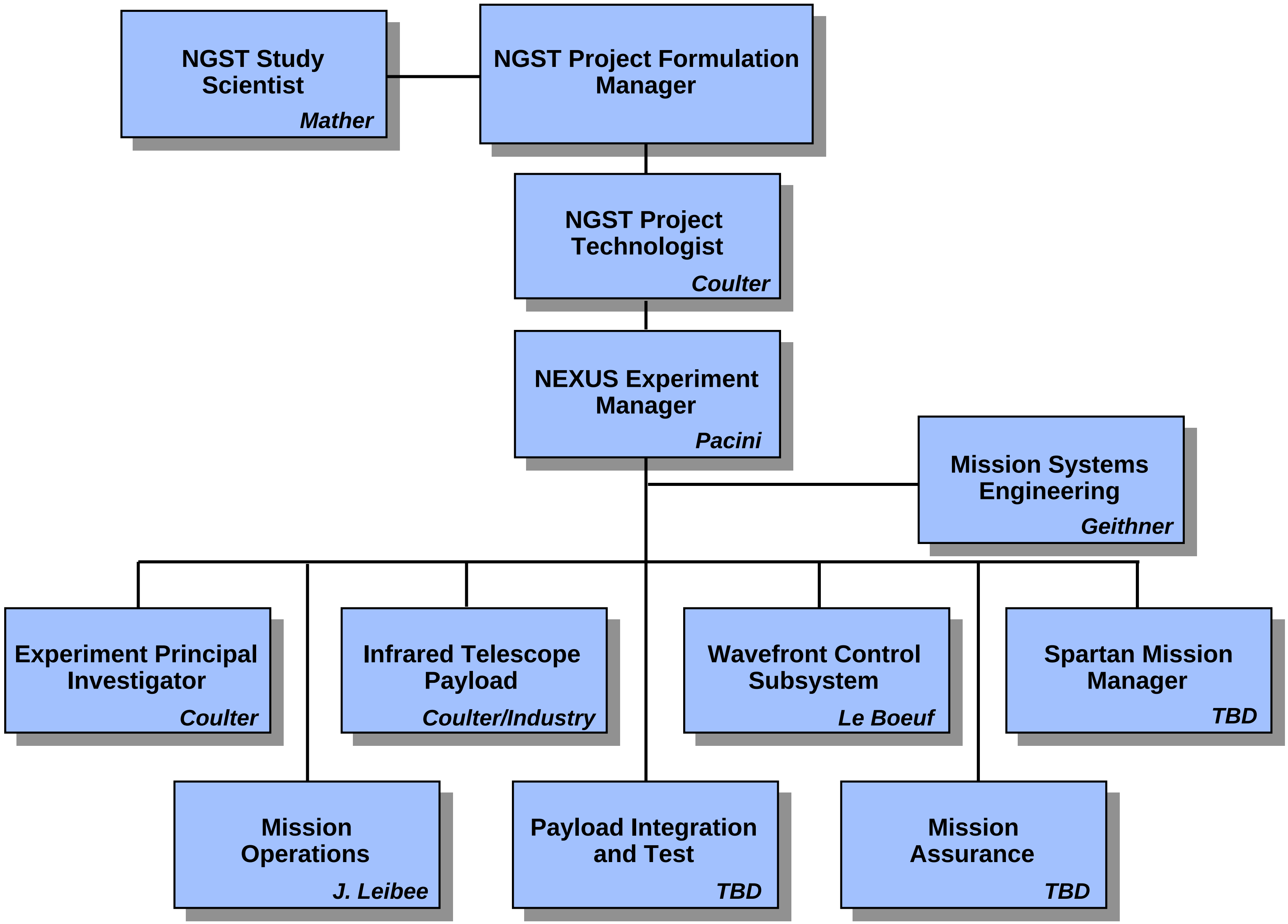
Pathfinder 3 Flight Experiment- NEXUS

- NEXUS- Precision deployment, optical control and diffraction limited imaging with an ≈2m diameter segmented IR telescope
  - NASA/Industry partnership
    - System contractor supplies "flight traceable" telescope
    - NASA team responsible for control system, S/C, ops, etc.
  - Collect data on:
    - effects of gravity release on optics
    - joint nonlinearity
    - vibration isolation
    - optical control system effectiveness
  - Validates key telescope system technology, integrated models and "art to part" design methodology
  - mid 2003 launch; ≈3 month duration; Spartan 400 S/C; $50M+ cost
  - Key demonstration of readiness to proceed to implementation phase
  - Actively seeking partnering opportunities



NEXUS

NEXUS Team



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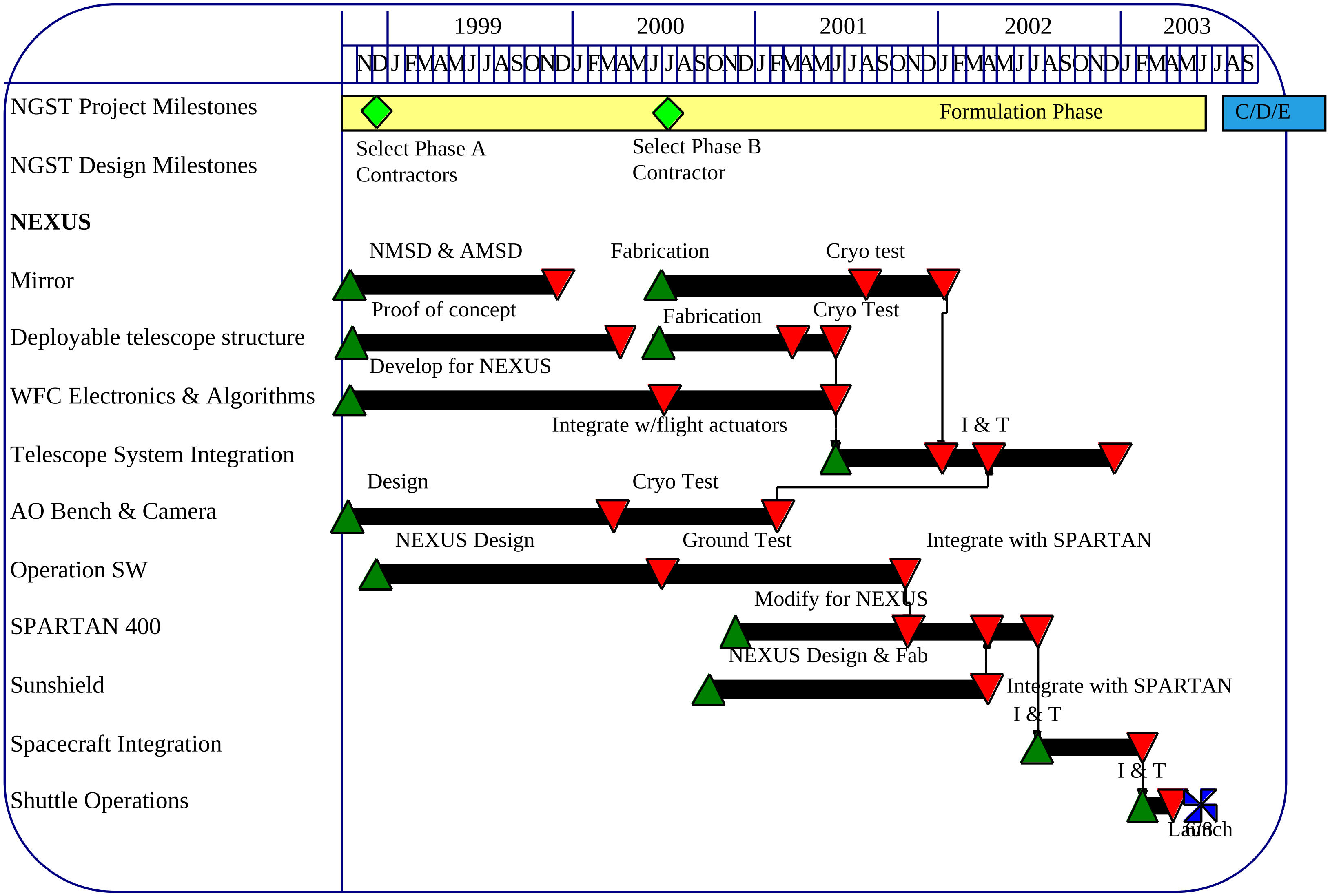
Strawman NEXUS Schedule



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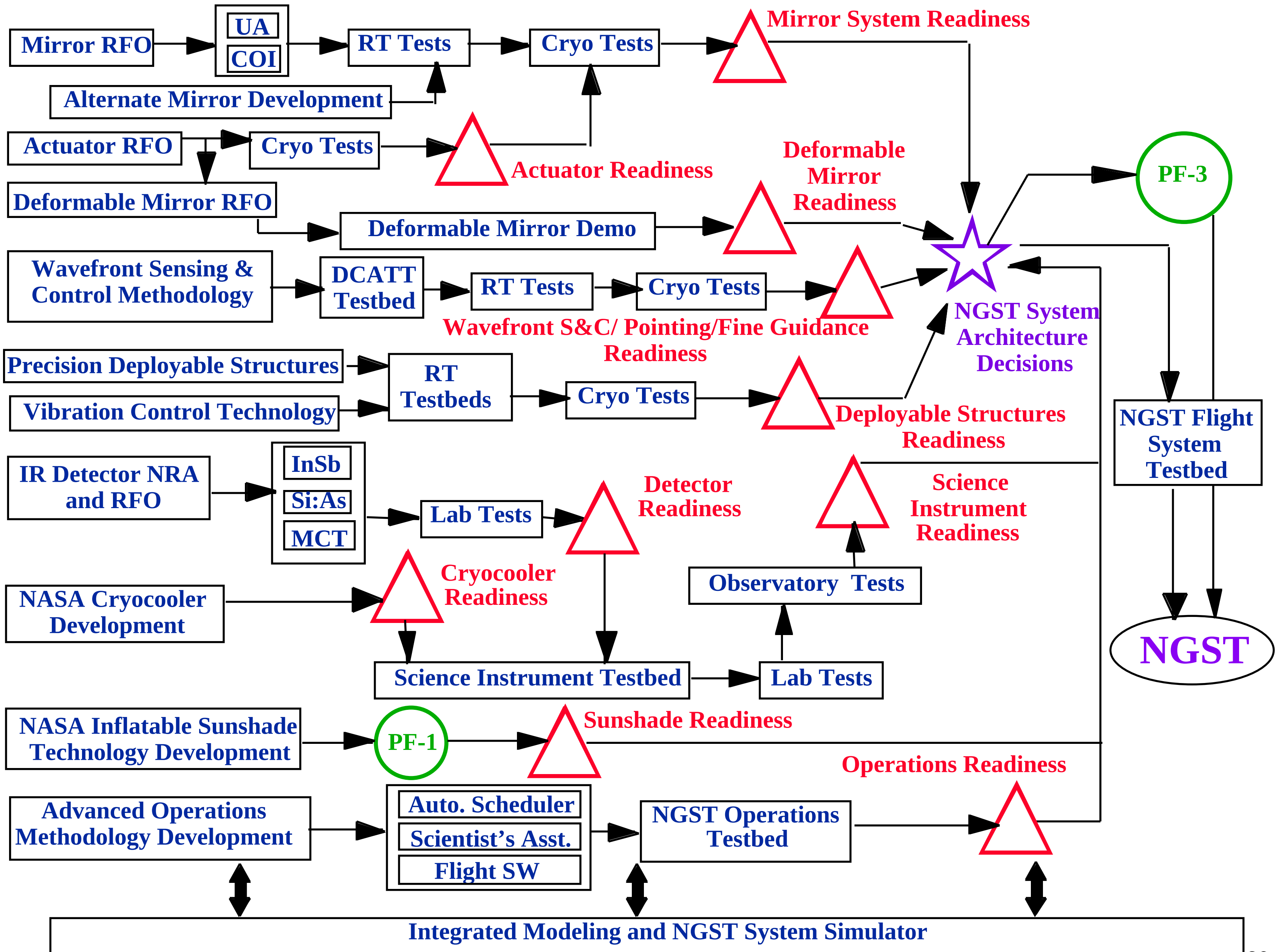
NGST Technology Development Roadmap



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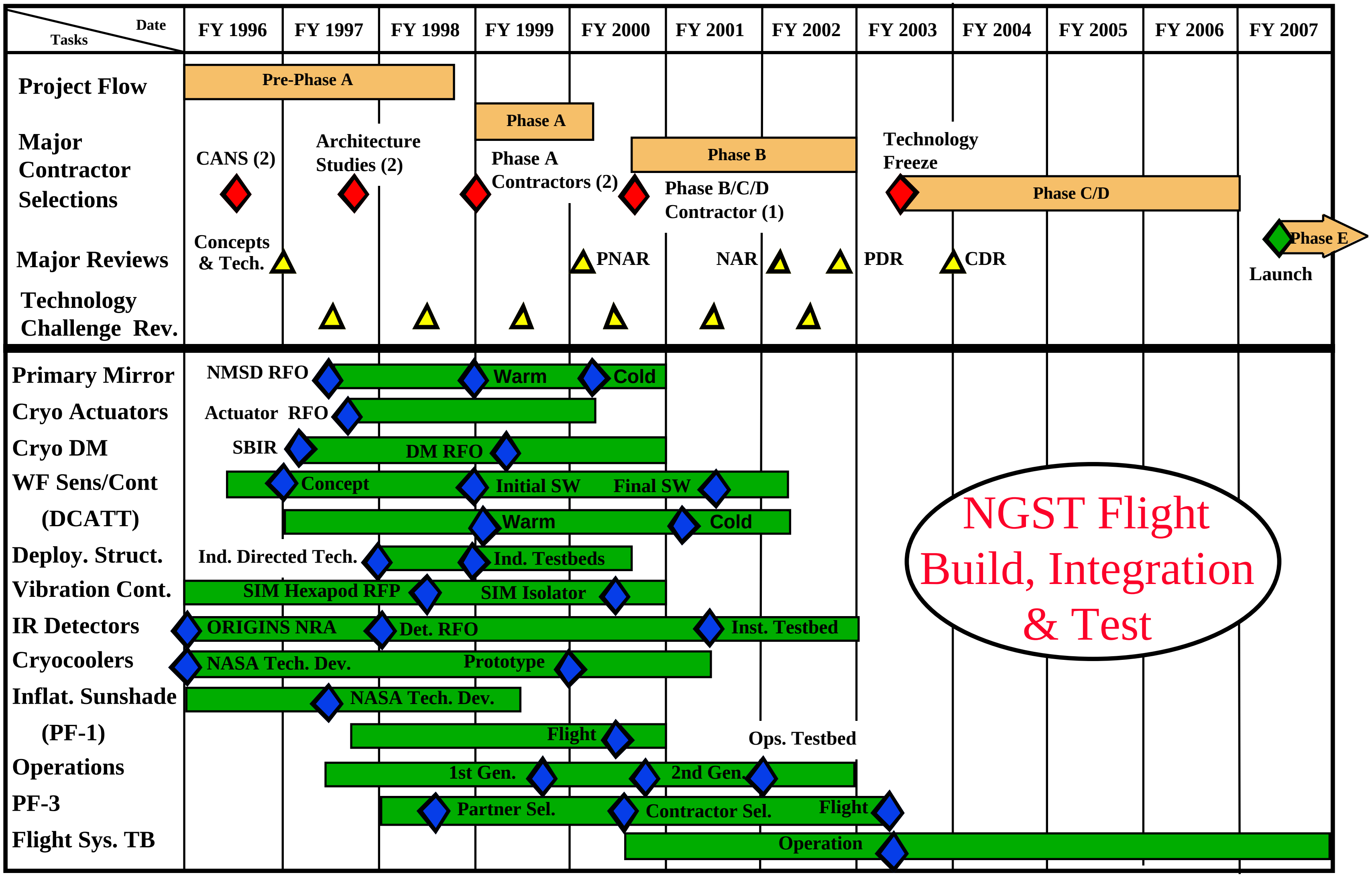
NGST Technology Development and Validation Schedule



Next Generation Space Telescope

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NGST Technology & Validation Budget ($M)

	FY97	FY98	FY99	FY00	FY01	FY02	FY03	NGST Total	*Other Total*	Grand Total
Primary Mirror	0.8	4.6	4.3	4.5				14.20		**14.30**
Other		*0.1*							*0.10*	
Cryogenic Actuators		0.8	0.25	0.4				1.45		**1.65**
Other	*0.1*	*0.1*							*0.20*	
Cryo Deformable Mirror			0.3	1.0				1.30		**2.25**
Other	*0.1*	*0.85*							*0.95*	
WFS & Control	0.3	3.2	3.8	4.0	1.0	1.0		13.30		**13.50***
Other		*0.2*	*	*	*	*			*0.20**	
Deployable Structures								0.00		**1.90***
Other		*1.9*	*	*					*1.90**	
Vibration Control								0.00		**3.00***
Other	*0.5*	*1.0*	*1.0**	*0.5**					*3.00**	
IR Detectors		0.3	0.4	1.0	2.9	2.9		7.50		**12.50**
Other	*2.22*	*1.39*	*1.39*	*	*	*			*5.00*	
Cryo-coolers			0.1					0.10		**2.30***
Other	*0.6*	*0.6*	*0.6*	*0.4*	*				*2.20*	
Lightweight Sunshade								0.00		**0.85***
Other	*0.1*	*0.75*	*						*0.85**	
Operations Methodol.		0.6	0.6	0.7	1.2	2.4		5.50		**6.10***
Other		*0.2*	*0.2*	*0.2*	*	*			*0.60**	
Misc. Technology Dev.	0.2	0.4	0.75	1.05	0.3	0.3	0.3	3.30		**37.9**
Add. Ind. Dir. Tech.*		*0.1*	*5.4*	*10.0*	*7.1*	*7.0*	*5.0*		*34.6*	
Pathfinder 1&2		0.5	1.5	1.4				3.40		**11.00**
Other			*3.8*	*3.8*					*7.6*	
Pathfinder 3			4.3	10	19	19	2.5	54.8		**54.80+**
Other			*TBD*	*TBD*	*TBD*	*TBD*	*TBD*		*TBD*	
Flight System Testbed				*	*	*	*		*	*****
NGST Total	**1.3**	**10.4**	**16.3**	**24.05**	**24.4**	**25.6**	**2.8**	**104.85**		
Other Total	***3.62***	***7.19***	***12.39***	***14.90***	***7.1***	***7.0***	***5.0***		*57.2+*	
GRAND TOTAL	**2.7**	**17.92**	**27.69**	**41.84**	**31.5**	**32.6**	**7.8**			**162.05+**

*** = Funds from "Add. Ind. Dir. Tech." line may be spent in these areas**
+ = Additional funding for PF-3 is anticipated from partnering agreements with other agencies

Next Generation Space Telescope

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NGST

NMSD UNIVERSITY OF ARIZONA TEAM

UNIVERSITY OF ARIZONA

THERMOTREX CORP

LOCKHEED MARTIN

COMPOSITE OPTICS INC

Next
Generation
Space
Telescope

LIGHTWEIGHT MIRROR TECHNOLOGY
UNIVERSITY OF ARIZONA

NGST primary mirror made from a glass membrane on an active rigid support

Concept: Achieve NGST shape accuracy and low-mass requirements by actively controlling the shape of a ploished glass membrane

Mirror shape control is made by many remotely controlled adjustment screws, and is based on measurements using star light

Current design predict shape accuracy of 0.012 λ rms for 8-m NGST at 1 μm, with of only 600 kg. (HST 2.4-m primary has mass>800 kg)

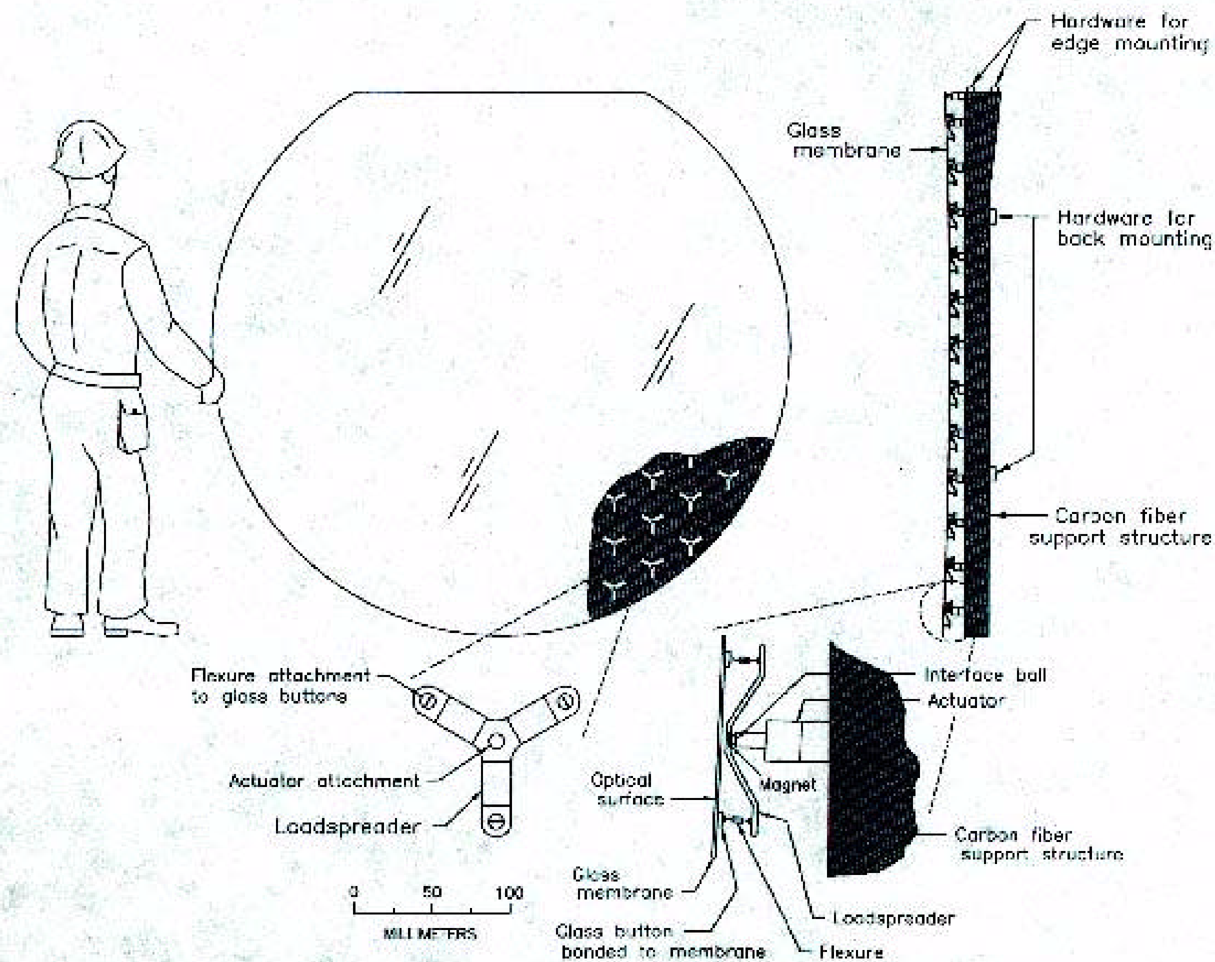
Technology has been demonstrated for 53-cm prototype

1-m prototype has demonstrated survival of acoustic launch loads

2-m demonstration currently being built, will be tested at 35K in mid-1999

This technology can provide the primary mirror for NGST as segments with any shape, or a single monolith, up to 8 meters in diameter using existing facilities

University of Arizona 2-m NGST Mirror System Demonstration



University of Arizona, ThermoTrex Corp, Lockheed Martin, Composite Optics Inc.

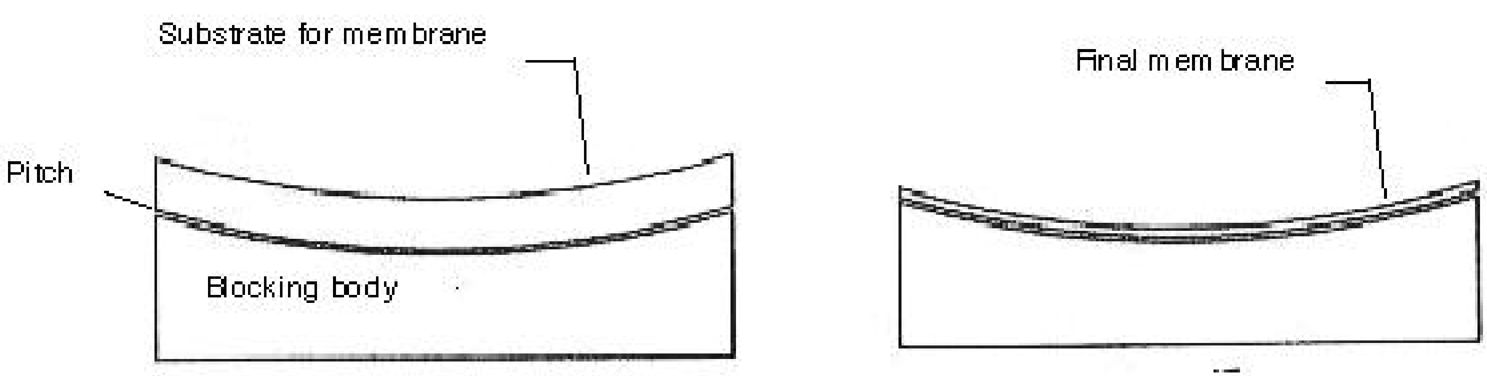
J. Burge
12/30/97

Thin shell fabrication

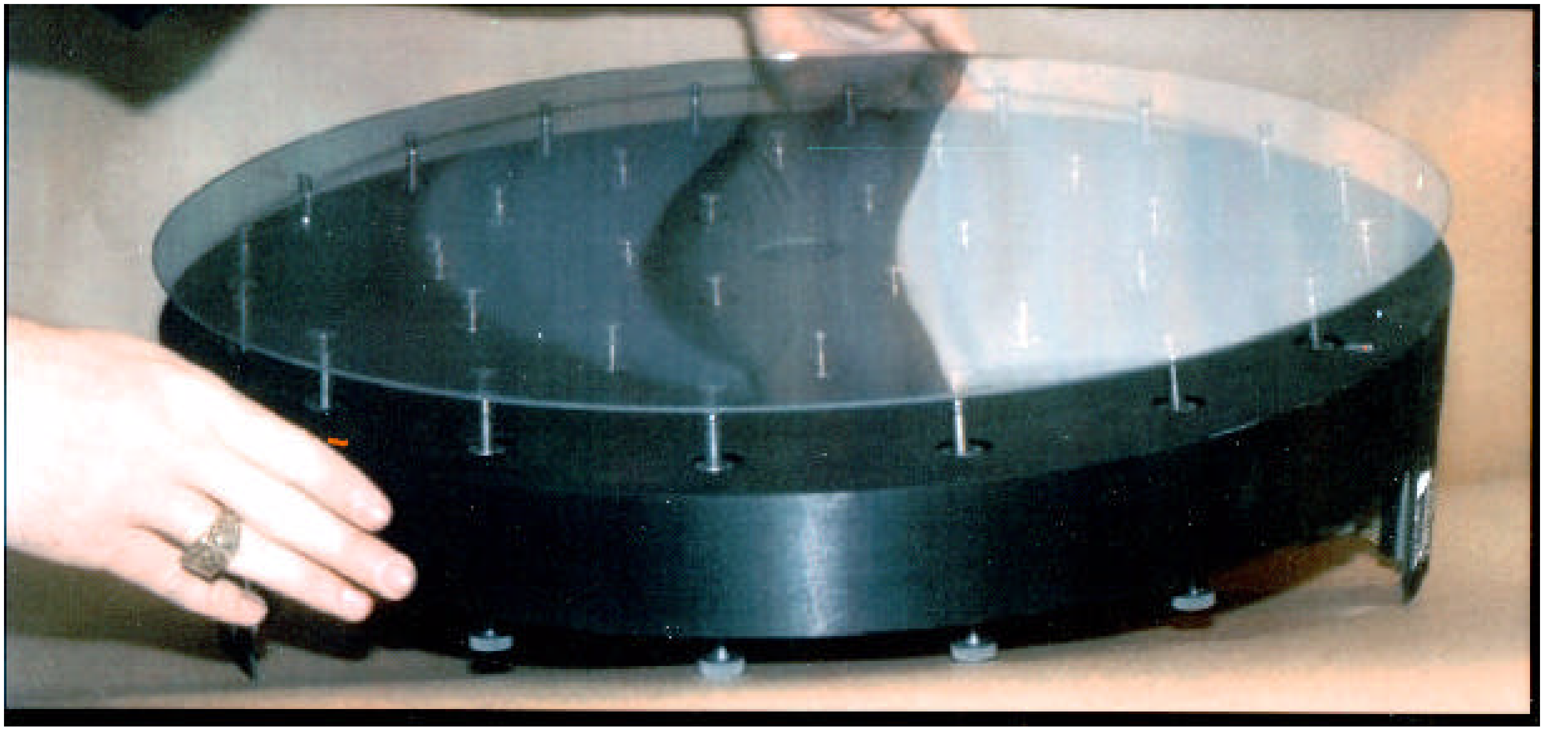
The concept is to work the glass while it is rigidly bonded in place

Sequence of operations for manufacturing concave glass membranes

- Generate and polish concave sphere into rigid blocking body
- Generate and polish convex sphere on back of relatively thick meniscus
- Attach the meniscus to the blocking body with pitch
- Generate membrane to near final thickness
- Grind and polish membrane to specified figure
- Warm to melt pitch, slide membrane off blocking body



Next Generation Space Telescope



Next
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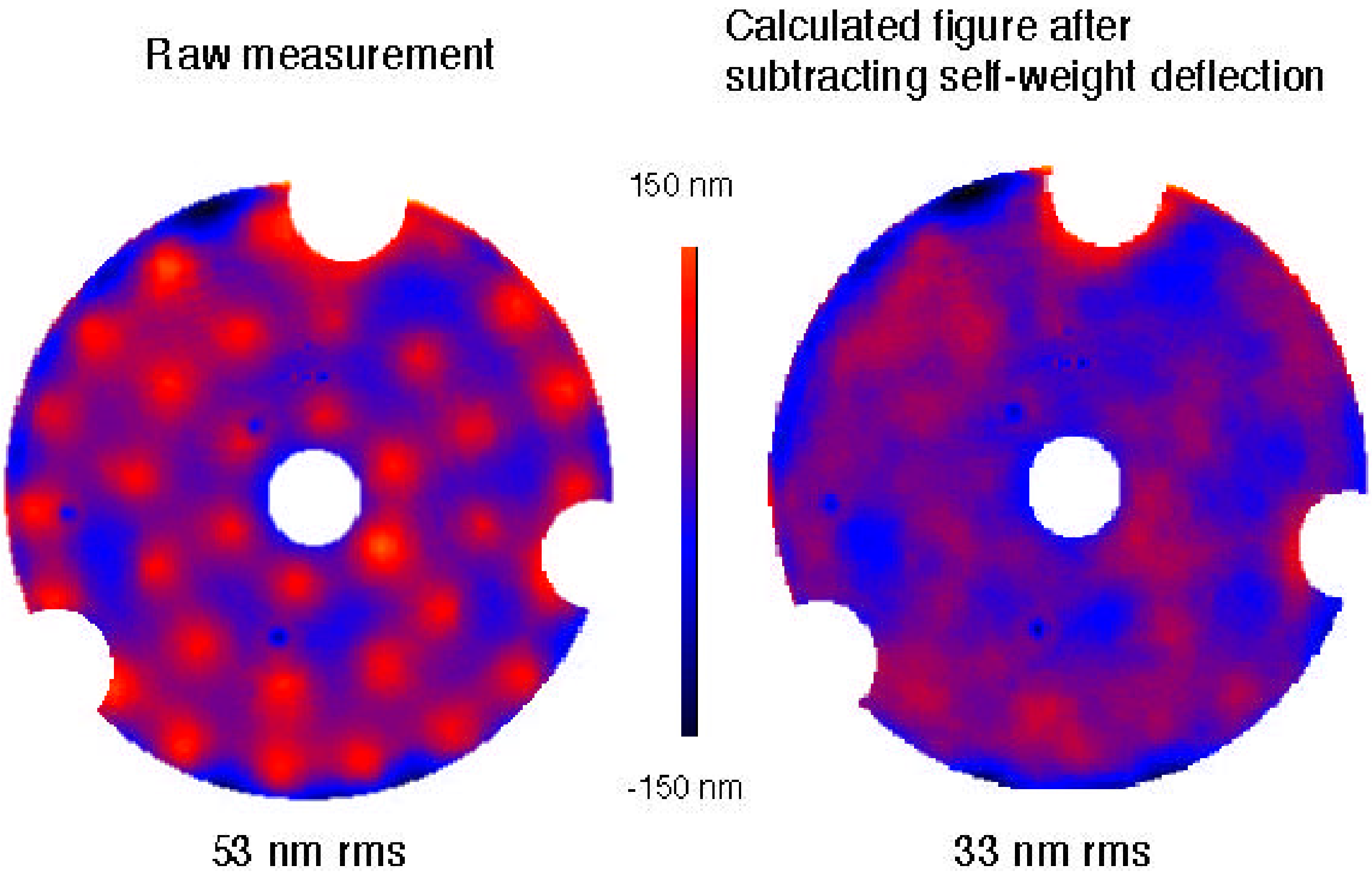
Telescope

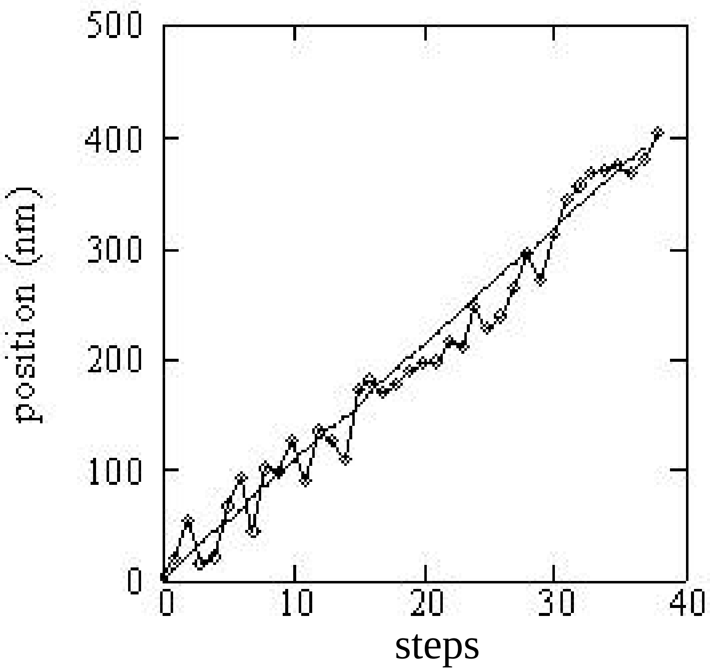


J. H. Burge, University of Arizona

NGST

Cryogenic actuators

- Early prototype designed and built by ThermoTrex and U of A (uses proprietary ThermoTrex mechanism)
- Concept demonstrated, needs optimization and design for production
- Achieves 25 nm resolution at 77K
- Requires zero hold power
- 5 mm total travel
- total mass of 72 grams



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Demonstration of survival of 1-m glass membrane

- 2.2 mm shell, sagged to 4-m radius
- supported on 75 dummy actuators, roughly 100/m^2, giving ~400 Hz fundamental frequency
- aluminum backing plate
- Hit with 3 dB over Atlas IIAS load in Lockheed Martin's acoustic test facility
- Membrane survived shipping mishap as well as acoustic test
-

NGST

Next Generation Space Telescope

Technology Readiness

Technology: ***ULTRA-LIGHTWEIGHT OPTICS*** — Readiness Level 06 needed

Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =	04		05		06				

Status: Two NMSD contractor teams completed PDR; modification of AXAF facility to accommidate cryo- testing under study

Technology: ***WAVEFRONT CONTROL*** — Readiness Level 06 needed

Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =		04	05		06				

Status: Computer simulation performed in FY97; DCATT testbed under construction

Technology: ***VIBRATION ISOLATION AND SUPPRESSION*** — Readiness Level 06 needed

Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =					06				

Status: Requirements definition in progress; monitoring ITP* isolator results; ≤1Hz modes not covered by ITP

*ITP= Interferometry Technology Program

Next Generation Space Telescope

Technology Readiness

Technology: *DEPLOYABLE STRUCTURES*					Readiness Level 06 needed ↓				
Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =		04		05	06				

Status: Funded under Iindustry Directed Technology Development option of architecture studies; Monitoring ITP results

Technology: *CRYOGENIC ACTUATORS*					Readiness Level 06 needed ↓				
Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =			05		06				

Status: RFO released; proposals submitted and evaluated; selection completed; negotiations to start; test facility under development

Technology: *INFLATABLE STRUCTURES*					Readiness Level 06 Needed ↓				
Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =		04		06					

Status: Technology development in progress ($750K) under JPL Inflatable Technology Program; Flight experiment planned

NGST

Next Generation Space Telescope

SRB

Technology Readiness

Technology: *DETECTORS*

Readiness Level 06 needed

Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =			05		06				

Status: Augmenting existing ORIGINS NRA ; RFO in FY'98; Industry Directed Technology Development funding as well

Technology: *CRYOCOOLERS*

Readiness Level 06 Needed

Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =			05		06				

Status: Monitoring progress at GSFC and JPL under Code SM Crosscutting Technology Program ; no current NGST funding

Technology: *INSTRUMENTS*

Readiness Level 06 Needed

Fiscal Year	'97	'98	'99	'00	'01	'02	'03	'04	'05
Planned program milestones TRL =			04	'05	06				

Status:Science Instrument Definition RFO released; prototype evaluations at GB observatory in FY'01